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RESEARCH REPORT

PERSONNEL ANALYSIS DIVISION

FINAL REPORT

of

RESEARCH PROJECT N/onr-39423, NR 152 129

THE DEVELOPMENT AND EVALUATION OF A METHODOLOGY FOR ESTABLISHING VISUAL REQUIREMENTS FOR NAVAL PERSONNEL

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SUMMARY

A methodology was developed which provides a feasible means of establishing visual requirements for battlestation assignments. The methodology consists of determining the relationship between performance of subjects on a job-sample test and various levels of artificially induced vision.

To evaluate the methodology a job-sample test was constructed and the relationship between performance and near visual acuity was determined by rather complex statistical procedures and also by simple graphical procedures.

As a result of the research conducted, the proposed methodology appears to provide a means whereby visual requirements can be rapidly and efficiently established. Because the graphical method of analyzing the experimental data proved to be feasible, it is proposed that technicians, under the direction of a professional psychologist can satisfactorily perform the task of gathering and analyzing the necessary data for inferring visual standards.

It was further found that visual standards established for a particular job under given lighting and working conditions would not necessarily be valid for other jobs and/or other lighting and working conditions.

A somewhat more detailed summary is provided in the following six pages.

SUMMARY

THE DEVELOPMENT AND EVALUATION OF A METHODOLOGY FOR ESTABLISHING VISUAL REQUIREMENTS FOR NAVAL PERSONNEL, final report of research conducted on Navy contract N7onr-39423, NR 152 129; a contract negotiated between the Office of Naval Research and the Purdue Research Foundation "to develop methodology for establishing vision standards for selected battlestation assignments aboard various types of naval vessels."

A survey of the literature revealed several approaches to the problem of establishing visual standards in industry and the Armed Forces. The methodology appearing to provide the most feasible means of establishing dependable vision standards was to establish vision standards based on experimental evidence relating vision to job performance. This method had been used successfully in industry where the relationship between the job performance of industrial workers and various visual functions had been studied experimentally. Using this general methodology, four major experiments were conducted to develop and evaluate a methodology providing a feasible means of establishing standards for Navy battlestation assignments.

The first experiment conducted was an exploratory study to determine the feasibility of constructing a job sample test from naval equipment. The test, which was developed on a small piece of naval equipment consisted of a subject raising a cover from a dial and reporting the dial reading as rapidly and as accurately as possible. The subject was scored both on the length of time required to report the reading, and on the accuracy of the report given. From the results of this phase it was concluded it would be feasible to construct a similar

job sample test using larger and more complex equipment.

The second phase of the program of research was conducted to study the relationship between the different visual functions, as measured by the Bausch and Lomb Ortho-Rater, and performance on a job-sample test developed on a rather complex piece of naval equipment. The subjects were 104 volunteers from elementary psychology courses at Purdue University. The job sample test was similar to that developed in Phase I. There were seven stations on which the subjects performed in sequence, and each subject repeated the sequence of seven stations ten times. Each station consisted of a dial, or dials, covered by a wooden lid. On the command "ready" the subject grasped the handle on a lid; on the command "now" the subject raised the lid and reported the reading as rapidly and accurately as possible. Performance was measured in two ways: (1) on the length of elapsed time between the command "now" and the subjects' response, and (2) the amount of error, if any, in the response. A sequence of ten readings was developed before the experiment, and all subjects performed on the same set of readings.

Analysis of the performance scores obtained showed the time scores were reliable measures of performance. Because of the nature of the data no conclusions were possible concerning the reliability of errors in reading the dials. The data were further analyzed to determine the relationship between the various visual skills measured by the Bausch and Lomb Ortho-Rater and performance on the job sample test which resulted in the conclusion there was no relationship between vision and job performance. However, it was felt the negative results were due to the visual characteristics of the sample of subjects and that

a similar study using subjects possessing visual skills covering the entire range of vision should be conducted.

On the basis of the results of the first two phases of the program of research, a third experiment, Phase III, was designed. This study was conducted to evaluate a methodology for setting visual standards which consisted of determining the relationship between vision, as measured by the Armed Forces Vision Tester, and performance on a job sample test, using subjects possessing a high level of visual skill, and reducing their vision by crossed-cylinder oblique lenses to obtain the range of vision necessary to determine the manner in which vision is related to job performance.

The job sample test used in this study was the same as that used in Phase II, except for certain modifications in the dials used. The test was administered in the same manner as in Phase II. The performance scores obtained in this experiment were the same as in Phase II. Ten highly motivated, well trained subjects performed ten times on each dial at each of five levels of vision.

This experiment was designed so that a complex statistical analysis could be made of the data, and also so that curves representing the relationship between vision and performance could be developed if the results of the statistical analysis showed a relationship between vision and job performance.

Both time and accuracy scores were first analyzed to determine the reliability of performance on the job sample test. The reliability of performance as measured by the time scores was extremely high. The reliability of the accuracy scores was less adequate. The data

were then analyzed using variance techniques and the results of these analyses showed vision was related to job performance. They also showed highly significant differences in performance on the different dials in the job sample test. From the results of these analyses it was concluded that curves representing the relationship between vision and job performance would have to be developed for each dial individually and that results obtained on one dial could not be generalized to another. Two curves, one for time and one for accuracy, were then developed for each dial showing the relationship between near visual acuity and performance on the job sample test.

On the basis of the results of Phase III, it was concluded the methodology developed and evaluated in the study provided a feasible means of determining the relationship between vision and job performance, from which visual standards can be easily and rapidly inferred.

However, two questions had arisen concerning the extent to which results obtained by the methodology developed in Phase III could be generalized. These were: (1) Would the results have been the same under all levels of illumination, and (2) would the results have been the same at different distances from the visual task. In order to answer these questions, Phase IV of the program of research was conducted.

In this experiment a job sample test was developed using one dial on the equipment used previously in Phase I. The experimental apparatus was constructed so that the level of illumination and distance of the subjects eyes from the task could be carefully controlled. The type of task, measures of performance and subjects used in the experiment were

the same as used previously in Phase III. In addition the techniques used in analyzing the data were the same as those used in Phase III.

From the results of this study it was concluded that both distance and illumination must be taken into consideration when establishing visual standards from performance curves. Curves developed from job performance under a given set of conditions of illumination and distance cannot be used to set standards for jobs performed under dissimilar conditions.

On the basis of the overall program of research the following conclusions were made:

1. The methodology evaluated in Phase III of the program of research provides a feasible means of establishing visual standards. Free-hand curves fitted to plots of vision scores versus job-performance can be used to describe the relationship between vision and job-performance. Further, the problem of obtaining a range of vision for certain visual functions was solved by the use of clip-on crossed-cylinder lenses. Of further importance is the fact that technicians, directed by a professional psychologist, would be able to apply the methodology in the collection of experimental data.

2. On the basis of the evidence obtained in Phase III, only very limited generalization of results from one visual task to other visual tasks can be made, because the trend of performance on different visual tasks was not the same at different levels of vision.

3. On the basis of the evidence obtained in Phase IV, results obtained under a given set of conditions, i.e., at a given level of illumination and at a given working distance from the visual task , cannot be generalized to other conditions because the trend of performance was not the same at different levels of vision for different conditions of illumination and distance from the visual task. Further these results point out the desirability of maintaining standardized conditions on a battlestation.

4. Although not within the realm of this study, the results of the program of research conducted appear to have implications for equipment design. The results of Phase III clearly indicate that certain types of dials are read faster and more accurately at all levels of visual acuity than other types of dials. These results warrant the conclusion that operators with poorer visual acuity could perform at a given level of proficiency on certain dials as well as, or better than, operators with better acuity could perform on other types of dials. Further, the efficiency of operators at all levels of acuity would be increased by the use of certain types of dials.

5. Other conclusions will be incorporated in "Supplement to Technical Bulletin #53-7," which for security purposes are classified.

6. A procedure for efficient use of the methodology was developed.

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THE DEVELOPMENT AND EVALUATION OF A METHODOLOGY FOR ESTABLISHING VISUAL REQUIREMENTS FOR NAVAL PERSONNEL

One phase of the long range program initiated by the Navy for establishing and validating physical requirements for naval personnel is concerned with the establishment of objective visual standards. In the interest of furthering this phase of the overall program, the Bureau of Naval Personnel, through the Office of Naval Research, negotiated a contract, N7onr-39423, with the Purdue Research Foundation to conduct a program of research within the area of visual standards.

Basic Objective

The basic objective of research contract N7onr-39423 was developed at a joint meeting held in July, 1952. The statement resulting from that meeting was as follows: "The basic objective of research contract N7onr-39423 is to develop methodology for establishing vision standards for selected battlestation assignments aboard various types of naval vessels."

With the above statement serving as a guide, four experiments were conducted in which a methodology for establishing visual standards was developed and evaluated.

Methodologies for Setting Vision Standards

A survey of the literature pertinent to the problem of establishing visual standards revealed several approaches in use. Although the approaches reported in the literature are concerned with visual standards in industry, it would appear the problems involved would be similar to those in military services. The

problems involved in establishing and validating physical requirements for personnel have long troubled industry as well as the military services. For purposes of discussion the approaches to establishing visual standards are grouped under three general headings.

Method 1. In this method "trained personnel"[1] arbitrarily establish visual standards on the basis of subjective judgements. These judgements may or may not be based on a visual analysis of the job. Visual standards set in this manner are likely to have little or no relationship to job performance. Although the importance of "good vision" is generally accepted (28), "poor procedures" such as this are widely used to determine what is good vision. A search of the literature revealed no studies evaluating the effectiveness of standards set in this manner.

Method 2. In this method professionally trained people arbitrarily set visual standards based on subjective evaluation of data obtained from a description of the visual factors of a job which have been reduced to physical measurement. Dimmick and Farnsworth (6), in a study conducted at the U. S. Naval Submarine Base at New London, Connecticut, used this approach. They made a survey of the visual factors involved in all interior submarine tasks which an enlisted man might be required to perform. They then attempted to describe the job in terms of critical visual tasks based on distance of the target from the operator, visual angle subtended

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1. The phrase "trained personnel" is used to designate individuals who set visual standards on some arbitrary, rule of thumb criterion. Such individuals may or may not be professionally trained to perform this function.

at the eye, frequency of the operation, brightness contrast, level of illumination, and visual discrimination required. On the basis of the evidence collected, clinical evaluations of the vis al requirements were made and standards set for the different jobs.

Method 3. The most scientific and undoubtedly most defensible visual standards are those set on the basis of experimental evidence relating vision to job performance. This method has been used successfully in industry where the relationship between the job performance of industrial workers and various visual functions have been studied experimentally. A number of studies using this approach have appeared in the literature (13, 16, 18, 25, 31). Visual standards set on the basis of results obtained in those studies still retain an element of subjective judgement in that standards of "good" and "poor" performance are based on judgements or ratings.

A variation of this methodology was used by Mitten and Fry (20) in an investigation of visual inspection performance. They attempted to determine the effect of impaired vision on roller inspection using artificially impaired vision. They found a definite impairment of performance on a job-sample test with anisometropia producting lenses and astigmatic producing lenses. Lenses with base-in and base-out prisms also produced pronounced differences in performance.

The methodological approach to establishing vision standards developed and evaluated in the program of research conducted under this contract was of the third type. Modifications similar to those used by Mitten and Fry were also evaluated.

RESEARCH CONDUCTED

As stated previously, four experiments were conducted in developing and evaluating a methodology for establishing visual requirements for naval personnel. For purposes of presentation, the four experiments are presented in sequence as Phases I, II, III, and IV of the program of research.

PHASE I

Purpose. The purpose of this exploratory phase of the program of research was to determine the feasibility of constructing a job-sample test from naval equipment. Further, the experience gained in conducting a preliminary experiment would be of considerable value in designing a major experiment.

The job-sample test. In order to achieve the purpose of this study, a job-sample test was developed using equipment which for security purposes will be referred to as Equipment A. The visual aspects of this job consist of reading the various dials on the equipment.

Covers were made for each of the dials contained in the equipment. The eleven dials in the job-sample were numbered in sequence. The task presented to the subject was to uncover the dial and report the reading on which the dial was set. Using this procedure eleven visual tasks were presented to the subjects. In administering the experiment, the subject was given two commands. On the command "ready" he grasped the handle on the cover and on the command "now" he removed the cover and read the dial as rapidly and accurately as possible.

Criteria of performance. Under operating conditions two criteria appear to be of importance in evaluating visual performance on a battle-

station. The operator must be able to respond to the visual stimulus, perceive the visual stimulus, and report the discriminations made, both quickly and accurately. These two measures, time and accuracy, which appear to be of utmost importance to the Navy in evaluating performance, were used as the criteria of performance on this job-sample test.

Two separate performance scores were obtained on each dial reading: a time score, and an accuracy score. The time recorded was the time elapsed between the command "now" and the report by the subject. The reading given by the subject was recorded, and this reading was compared with the dial setting to determine the accuracy score. The reading was scored incorrect if it differed at all from the exact reading. No attempt was made to assess the errors qualitatively in terms of their magnitude.

Methods of Procedure

Subjects. Nine subjects were used in this experiment. All were volunteers from graduate students in psychology at Purdue University. The only criterion of selection of the subjects was their availability to perform in the experiment. Each of the subjects was given a short training period on the job-sample test and instructed to read the dials as rapidly and accurately as possible. No subject had "poor" vision on the basis of his Ortho-Rater scores.

Administration of the experiment. Each subject read the sequence of the eleven dials in the job-sample test ten times. The apparatus was placed on a table 36" high. The subject stood in front of the apparatus. On the command "ready" the subject grasped the handle on the cover on the dial. On the command "now" he removed the cover and read the dial as rapidly and accurately as possible. This procedure

was repeated for each dial until the sequence of eleven dials was read. The subject was then seated while the dials were reset. This process was continued until the sequence of eleven dials was read ten times.

The apparatus was illuminated by an incandescent bulb. The level of illumination on the apparatus was maintained at a relatively high level.

<u>Results.</u> The average time performance of each of the subjects on the nine dials in the job-sample test are presented in Table 1.

Table 1

Average Length of Time in Minutes to Read Equipment A Dials for Nine Subjects.

	Dial Read								
Subjects	3	4	5	6	7	8	9	10	11
1	.055	.072	.075	.166	.103	.052	.116	.115	.055
2	.044	.087	.076	.113	.132	.052	.099	.107	.081
3	.039	.062	.064	.108	.116	.044	.081	.105	.050
4	.034	.051	.066	.080	.070	.040	.068	.065	.041
5	.032	.046	.055	.052	.043	.043	.049	.051	.041
6	.032	.050	.066	.065	.068	.050	.063	.059	.053
7	.032	.059	.056	.064	.071	.039	.070	.098	.048
8	.031	.044	.049	.063	.064	.032	.05[illegible]	.066	.033
9	.027	.051	.059	.074	.067	.035	.079	.100	.048

Inspection of the data in Table 1 indicated a considerable amount of variability in the performance of the different subjects. This indicated that performance on a job-sample test of this nature could be measured on the basis of time required to perform the task.

The accuracy scores could not be evaluated due to the fact that very few errors were made. From this result it was concluded that either the job-sample test must be increased in difficulty and/or subjects with greatly reduced vision be tested before the criterion of accuracy could be used to evaluate performance.

Conclusions. On the basis of the results obtained in this exploratory experiment it was concluded that a job-sample test of the type evaluated provided a feasible means for developing a methodology for establishing vision standards. Furthermore, it was concluded that it would be feasible to make use of larger and more complex equipment in developing a job-sample test.

PHASE II

On the basis of the results obtained in Phase I of the program of research, further research designed to provide information concerning the basic objective of the contract was initiated. This phase of the program of research, Phase II, was our first major experimental effort.

Purpose. The purpose of this experiment was to investigate the relationship between the different visual functions measured by the Bausch and Lomb Ortho-Rater, and performance on a job-sample test developed on equipment which for security purposes will be referred to as Equipment B. It was hoped to arrive at a visual profile for the particular jobs contained in the job-sample test, and the family of jobs related to it.

The Job-Sample Test. The job-sample test consisted of dials contained in equipment B. This equipment consisted of three sub-units which will be referred to as Equipment B1, B2, and B3. The job-

sample test was developed with the following considerations in mind: the total test require no more than 50 minutes; the test consist of job elements heavily loaded with visual elements; it consist of job elements important to the job as a whole; the subjects be busy as much of the time as possible; a minimum of ten measurements be taken on any one station for reliability purposes; and a minimum of time be required to learn the job-sample test.

The final form of the test consisted of seven stations with a total of thirteen separate dials. The stations containing more than one dial were treated as one task. In other words, if a station contained three dials, one score was obtained for the three dials. Each station was covered with a wooden lid. The task of the subject was to remove the lid and report the dial reading, or readings, as accurately as possible.

Criteria of Performance. The criteria of performance on this job-sample test were the same as those in Phase I: time and accuracy (See page 5).

Methods of Procedure

Subjects. One hundred four male subjects were used in this experiment. All were volunteers from elementary psychology courses at Purdue University. It was expected this group of subjects would have a distribution of visual skills typical of that to be found in the general population.

Administration of Experiment. The vision of each subject was measured by the Bausch and Lomb Ortho-Rater immediately prior to administering the job-sample test. The Ortho-Rater was administered in accordance with standard testing procedures (33).

The job-sample test was administered with the subject positioned in front of the dial, or dials, to be read. On the command "ready" he grasped the handle on the cover, and on the command "now" he reported the setting of the dial, or dials. Using this procedure the subject was kept busy throughout the experimental procedure. The actual testing procedure was as follows:

1. The subject was given the battery of vision tests.

2. The subject was given an introductory talk about the nature of the job-sample test, and each of the seven stations was described in detail.

3. The subject was given two trial runs across all seven stations. Whenever the subject made an error, it was discussed and the correct reading was explained to him.

4. The actual job-sample test was administered to the subject. The sequence of seven stations was repeated ten times.

The order of readings was the same for all subjects. The readings were selected so the dials in the job-sample test could be reset easily and rapidly. This was necessary in order to administer the test in 50 minutes, which was the maximum time a student could be scheduled.

In the test situation the subjects were advised to wear the same eye correction, if any, they normally wore while reading. It was felt atypical performance might result if those subjects normally using corrected vision were required to perform at other than their usual level of vision. Each subject was tested on the Ortho-Rater with the same correction, if any, worn during the experiment.

Results. In order to investigate the nature of the test itself, the reliability of the job-sample test was estimated by correlating total score on the odd against the total score on the even trials on the job-sample test. A standard correlation procedure was used (19). The reliability coefficients were then "stepped up" using the

Spearman-Brown Prophecy formula (11). The resulting coefficients of reliability are given in Table 2.

TABLE 2

Reliability of Job-Sample Test

Criterion measure	Station	Reliability Coefficient
Time	1	.87
Time	2	.33
Time	3	.93
Time	4	.84
Time	5	.89
Time	6	.91
Time	7	.92
Time	Total Test	.95
Accuracy	Total Test	.43

On the basis of the obtained coefficients of reliability it was concluded the time scores obtained were reliable measures of performance. No statement concerning the reliability of performance as measured by the accuracy scores was possible on the evidence presented. The reliability coefficient of these scores was low, but investigation of the data showed that few errors were committed, and that those committed were for the most part committed on two stations. Therefore, the obtained reliability coefficient is, in all probability, an underestimate of the true reliability.

Variability. In order to investigate the variability of the obtained performance scores, the variances of the different stations were computed. The variance of each of th stations in the job-sample

test is presented in Table 3.

TABLE 3

Variance of Time-Scores on
Each of Seven Stations

Station	Variance
1	24.38
2	20.21
3	44.93
4	28.60
5	178.92
6	5658.90
7	1389.00

From the obtained variances of the different stations it was concluded that stations 5, 6, and 7 accounted for the major portion of the variance of the total test. Inspection of the stations in the job-sample test showed the dials in stations 1, 2, 3, and 4 differed considerably from the dials in stations 5, 6, and 7. On a logical basis it appeared that much more interpretation was required to read the dials in stations 5, 6, and 7. Therefore, it was decided to analyze the data using four criteria as perhaps being indicative of job success. The four criteria were: (1) time on all seven stations (ten runs); (2) time on stations 1, 2, 3, and 4 (ten runs); (3) time on stations 5, 6, and 7 (ten runs); (4) accuracy score on all seven stations (ten runs).

<u>Predictors of the criteria.</u> The predictors of the criteria were the visual functions measured by the Bausch and Lomb Ortho-Rater. The twelve "visual skill" scores obtained from the Ortho-Rater are given in Table 4.

TABLE 4

Ortho-Rater Functions

1. Far phoria vertical - FPV
2. Far phoria lateral - FPL
3. Far acuity both eyes - FAB
4. Far acuity right eye } - combined into best eye score, FABE
5. Far acuity left eye }
6. Far depth perception - DP
7. Far color vision - FC
8. Near acuity both eyes - NAB
9. Near acuity right eye } -combined into best eye score, NABE
10. Near acuity left eye }
11. Near phoria vertical - NPV
12. Near phoria lateral - NPL

Four and five, and nine and ten were combined: this resulted in ten predictor scores.

Statistical analysis. The first step in the analysis of the data was to compute the correlation of each of the ten predictor variables with each of the four criteria. The correlation coefficients obtained using a standard correlation procedure (19) are presented in Table 5.

TABLE 5

Correlation of Ortho-Rater Functions With Criteria of Performance on Job-Sample Test*

Ortho-Rater Function	Time Score Total Test	Time Score Stations 1,2,3,4	Time Score Stations 5,6,7	Accuracy Score Total Test
FPV	-.12	-.04	-.12	.16
FPL	-.04	-.14	-.02	-.08
FAB	.10	.08	.10	.02
FABE	.04	.01	.04	-.05
DP	-.03	.04	-.04	.08
FC	-.10	-.03	-.10	-.17
NAB	.16	.07	.17	-.06
NABE	-.02	-.09	-.01	-.05
NPV	.19	.03	.20	.06
NPL	.01	-.13	.03	-.11

* The signs of the obtained correlation coefficients are reversed in this table because high vision score represents good vision whereas low time score represents good performance.

Inspection of the data in Table 5 indicated little or no relationship between any of the Ortho-Rater functions and performance on the job-sample test. However, the possibility that factors other than vision had affected performance had to be considered. Therefore, it was decided to correlate Ortho-Rater scores with performance on the job-sample test holding the effect due to intelligence constant. American Council on Education (ACE) scores were available for 46 of the subjects that participated in the experiment. As performance on the ACE test is highly correlated with intelligence, Ortho-Rater scores were correlated with performance on the four criteria holding the effect of ACE score constant. The resulting partial correlations are given in Table 6.

TABLE 6

Partial Correlation of Ortho-Rater Scores With Performance on the Job-Sample Test Holding ACE Score Constant*

Ortho-Rater Function	Time Score Total Test	Time Score Stations 1,2,3,4	Time Score Stations 5,6,7	Accuracy Score Total Test
FPV	-.17	-.20	-.16	.02
FPL	-.20	-.08	.04	-.09
FAB	.21	.11	.22	.03
FABE	-.10	.02	.11	-.02
DP	.14	-.01	.16	-.02
FC	-.14	-.05	-.15	-.06
NAB	-.13	.02	-.16	-.03
NABE	.09	.08	.09	-.01
NPV	.20	-.07	-.24	-.14
NPL	.02	.02	-.02	.19

* See footnote Table 5

It was further decided to correlate Ortho-Rater scores with job performance holding the effect of mechanical aptitude constant. Scores on the Purdue Mechanical adaptability were available for 63 of the subjects who participated in the experiment. Ortho-Rater scores were correlated with performance on the four criteria holding the Purdue Mechanical Adaptability scores constant. The resulting partial correlations are given in Table 7.

TABLE 7

Partial Correlation of Ortho-Rater Scores With Performance on the Job-sample Test Holding Mechanical Aptitude Test Scores Constant*

Ortho-Rater Function	Time Score Total Test	Time Score Stations 1,2,3,4	Time Score Stations 5,6,7	Accuracy Score Total Test
FPV	-.13	-.05	-.14	-.19
FPL	-.05	-.15	-.03	-.10
FAB	.09	.07	.09	.00
FABE	.03	.00	.03	-.07
DP	-.03	.04	-.04	.08
FC	-.11	-.04	-.11	-.19
NAB	.17	.07	.17	-.05
NABE	-.01	-.08	.00	-.03
NPV	.19	.03	.21	.07
NPL	.01	-.14	.03	-.12

* See footnote Table 5

Consideration of the partial correlations in Tables 6 and 7 resulted in the conclusion the data offered no evidence that vision was related to performance on the job-sample test.

In designing the experiment it was anticipated that near visual acuity would show the highest degree of correlation with job performance due to the fact the task presented in the job-sample test was performed within the range of near point vision. However, analysis of the near visual acuity scores of the subjects in the experiment showed the range of vision was restricted to relatively high levels of vision. In addition, the distribution of the other visual skills of the subjects was restricted to a narrow range of vision.

Because of this restricted range of vision in the subjects used in the experiment it was unlikely any great degree of relationship between vision and performance could be demonstrated, as previous studies (26,28,29,31) have shown such a relationship to be more apparent at the lower levels of vision. The distributions of the visual skills measured by the Ortho-Rater of the subjects used are contained in Appendix A.

Conclusions. On the basis of the evidence presented in this study the following conclusions appeared warranted:

1. Time scores on the job-sample test were reliable measures of performance.
2. Performance on a job-sample test can be measured and evaluated.
3. No relationship between vision and job performance was demonstrated.
4. It would be of value to conduct another experiment similar to the one reported here, but with a wider range of vision.

PHASE III

Purpose. On the basis of the results obtained in the first two phases of the program of research, Phase III was initiated. The purpose of this study was to investigate a methodology for setting visual standards. The methodology consisted of determining the relationship between vision, as measured by the Armed Forces Vision Tester, and performance on a job-sample test, using subjects possessing a high level of visual skill and reducing their vision using crossed cylinder oblique lenses to obtain the range of vision necessary to determine the manner in which vision is related to job performance.

The job-sample test. The job-sample test used in this study was very similar to that used previously in Phase II of the program of research (See page7). The job-sample test consisted of ten different types of dials contained in Equipment B. The ten dials selected as the job-sample test were representative of all the dials contained in Equipment B1,B2,B3. These dials represented the visual tasks involved in four battlestation assignments. In addition, certain of the dials used are common to many jobs throughout the Navy.

The job-sample test was administered by placing a wooden lid over each of the dials and having the subject remove the lid and read the dial. Each lid was constructed with a handle so the subject could easily and quickly remove the cover from the dial. In the test situation the subject was given two commands. On the command "ready" he grasped the handle on the cover, and on the command "now" he removed the cover and read the dial setting as quickly and accurately as possible. The dials were set on pre-determined, randomly selected

readings.

The test was administered with the subject in the position from which operators normally work under battle conditions. This position was held constant by use of a barrier to prevent the subject from getting closer to the dial than the normal operating position.

The apparatus was illuminated by both daylight and overhead illumination. This resulted in a variation of illumination on the apparatus. However, because of the relatively high levels of illumination involved, the variation in illumination should have had comparatively little effect on performance (30).

Criteria of performance. The criteria of performance on the job-sample test were the same as those in Phase I and II: time and accuracy (See page 5).

The time recorded was the time elapsed between the command "now" and the first report by the subject. A maximum time of one-half minute was allowed to read a dial. The reading given by the subject was recorded, and this reading was compared with the dial setting to determine the accuracy score. The reading was scored incorrect if it differed in any way from the exact reading. No attempt was made to assess the error according to its magnitude. In those very few instances where a subject was unable to read a dial in one-half minute, the time score was recorded as fifty one-hundredths of a minute and the reading was recorded as being in error.

Subjects. Ten male subjects were used in this experiment. These ten subjects were selected from graduate students in psychology at Purdue University. A total of 15 students were refracted by a graduate

optometirst[2], and from the total, ten subjects were chosen. The choice was based soley on the visual characteristics of the students. The ten subjects used were those who had the least visual difficulty without spectacles and could be corrected to 20/15 or better at near point vision with the appropriate optical corrections. No student who needed any large degree of astigmatic correction was selected, since the clip-on lenses used to reduce vision produced an astigmatic error and atypical performance might result from a subject normally possessing any great degree of astigmatism. All subjects were fitted with the appropriate spectacles and these spectacles together with the proper clip-on lenses were worn whenever the subject was participating in the experiment. The prescriptions for the spectacles worn by each subject are given in Appendix B.

The subjects were not considered as a sample of the general population but rather as a sample of a population of above average intelligence, with a reasonable degree of sophistication in the area of experimental psychology, and possessing certain visual characteristics. The subjects were paid for participating in the experiment. It was assumed that sophisticated subjects, paid for their services, would be more highly motivated in their performance on the job-sample test than volunteer subjects.

Design of experiment. The job-sample test, a modification of that used in Phase II of the program of research, appeared to meet the needs

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2. The subjects were refracted by Dr. Merrill J. Allen, School of Optometry, Ohio State University. The subjects used were chosen on the basis of his recommendations.

for the problem to be studied in this experiment. When the job-sample test was completed and the criteria of performance determined, it was necessary to adapt a mathematical model to analyze the data and plan the administration of the experiment.

The basic mathematical model used was a factorial analysis of variance design with the three dimensions of ten subjects, five levels of vision, and ten dials, with ten replications. This design provided a sensitive test for the effects of subjects, levels of vision, and dials.

In order to meet the assumptions of this type design, it had to be randomized (17). Therefore, the ten dial readings in each cell were selected using a table of random numbers (10). In addition, the order in which each cell of ten readings was given to a subject was randomized using a table of random numbers (7, pp. 378-382), so as to randomly distribute any effect on performance arising from extraneous factors throughout the design.

Because it was necessary to obtain vision measurements on a subject immediately prior to being tested on each set of ten readings, administration of the experiment by cells provided the most efficient means of obtaining the necessary vision measurements and collection of the experimental data.

<u>Method of obtaining range of vision.</u> There are two methods whereby a wide range of visual acuity may be obtained for experimental purposes. These two methods are: (1) screen people from a population to find subjects with the necessary range of vision, or (2) use subjects with higher levels of acuity and reduce their acuity by artificial means. The first procedure is generally not feasible due to the fact that generally a very small percentage of individuals with low levels of visual acuity are available (See Phase II). Further, a job-sample test often involves a

considerable amount of equipment and cannot be installed in a place convenient to use subjects screened from other populations. Because a wide range of vision generally cannot be easily obtained by the first method, a methodology based on the second would be of much greater value.

In a joint conference, members of the research staff at Purdue University and Dr. Henry Imus and Dr. Glen Fry of the Armed Forces Vision Committee concluded that a method developed and used extensively by Dr. Fry in his previous research provided the most feasible means of producing a wide range of visual acuity. This method consisted of placing crossed cylinder lenses in front of the subjects' eyes, which was accomplished by having the crossed cylinder lenses mounted in frames that clipped on to the spectacles fitted to each subject. The type of crossed cylinder lens used was one with plus power in one principal meridian and an equal amount of minus power in the other principal meridian. The two principal meridians were at right angles to each other and 45° from the vertical.

A lens of this type produces an astigmatic error. However, the effect of the crossed cylinders is the same as throwing the eye out of focus by plus or minus spheres. Such spheres blur vision in the same manner as if the eyes were over or under accommodated. The only way a subject can overcome this astigmatic error is "to accommodate simultaneously for each meridian separately, which is practically an impossibility" (4, pp.188;24 p.144). Thus the error produced can be compared to astigmatism occurring naturally in a pair of eyes (20).

The amount of astigmatic error produced in the subjects ranged from

no error to 4.00 diopters. The prescriptions for the clip-on lenses and the amount of astigmatic error produced by each are contained in Appendix C.

The method of crossed cylinders was used in preference to other methods because the subject is unable to accommodate for the optical error produced by the crossed cylinder lenses and little or no eye strain results from their use. However, the question of difference in performance of two subjects, one naturally possessing a low level of visual acuity and the other who naturally possesses normal visual acuity which has been altered by crossed cylinder lenses to the same low level, remains unanswered. The writer feels this question will have to be answered on the basis of experimental evidence. However, it would appear safe to assume, that when all other factors are equal, a subject with artificially poor vision would perform less well than a subject with naturally poor vision, since the subject with naturally poor vision has had many years of experience to learn to compensate for his poor vision by using visual cues more effectively. In other words, because of his long period of learning experience, the subject with naturally poor vision should be more proficient. Therefore, visual standards set by this method may be in error, but any such error would likely be too stringent, which in effect would be an error in the conservative direction.

Administration of the experiment. This experiment was conducted over a ten day period. Each subject was scheduled for 1½ hours testing time per day. The first test period for each subject was spent in training him on the ten dials contained in the job- sample test. On the succeeding nine test periods he was tested according to the pre-determined order of cells. The time required to administer each cell was approximately 15 minutes. The procedure for administering each cell was as

follows:

1. The appropriate lenses were clipped onto the fitted spectacles worn by the subjects throughout the experiment.

2. The subject was tested on the Bausch and Lomb Ortho-Rater in accordance with standard administration procedures (33).

3. The subject was tested on the Armed Forces Vision Tester in accordance with standard administration procedures (32).

4. The subject was given the following instruction concerning the criteria of performance: "Two measures of performance will be recorded--the time it takes you to read the dial, and the accuracy of the reading you give. Therefore, read the dial as rapidly and as accurately as you can."

5. The subject was given five to ten practice readings on the dial to be read, the number of practice readings given depending on the difficulty level of the dial.

(6) The ten readings in the cell, which had been selected using a table of random numbers, were administered. The test was administered by having the subject remove the lid on the command "now", report the dial reading, and then step back and turn his head while the experimenter set the dial on the next reading and replaced the lid. He then resumed the normal operating position for the next reading.

Treatment of Data

Reliability of the job-sample test. The first step in the analysis of the data was to determine the reliability of the job-sample test to determine if it was a reliable measure of performance. The reliabilities of both time and accuracy scores were computed for both the total test and for each dial individually. This was accomplished by correlating the performance on the odd numbered replications in the cells against performance on the even numbered replications in the cells. A standard correlation procedure (19, p. 96) was used. The obtained correlation coefficients were corrected using the Spearman-Brown prophecy formula (11, p. 419).

<u>Analysis of variance of time scores.</u> The time scores recorded in this experiment were first analyzed using a factorial analysis of variance design. The ten subjects were treated as a sample of a population. The ten dials were treated as a population of dials and the five levels of vision were treated as a fixed population.

The first step in the analysis was to test the data for homogeniety of variance, as homogeniety of variance is a basic assumption of the design. The Bartlett test for homogeniety of variance described by Edwards (7, p.196) was used to make the test on the raw time scores. As this test showed the variance of the raw data to be heterogenous, the data were transformed to meet the assumption. The transformations made were decided upon from estimations of the proper transformation using the procedures outlined by Bartlett (2). The log log transformation of the raw time scores met the assumption of homogeniety of variance, and this transformation was used in the subsequent analysis. The Bartlett tests performed and the transformations made are discussed in Appendix D.

After meeting the assumption of homogeniety of variance, the analysis proceeded in a manner similar to that discussed by Lindquist (17). The significance of the difference between the means of each of the main effects of subjects, dials, and levels of vision was tested as was each of their first and second order interactions.

<u>Analysis of variance of accuracy scores.</u> The accuracy scores recorded in this experiment were also analyzed using a factorial analysis of variance design. Each reading given in the course of the experiment was considered correct only if the subject read the exact value at which the dial was set; any deviation from the exact setting was counted as an error. Using this criterion, the percentage of correct readings in each cell of ten

readings was calculated. These percentages were transformed into angles, expressed as degrees, using Snedecor's arc sine transformation (23, pp. 492--494). The percentages thus transformed were analyzed in the same manner as the time scores, except that only one value per cell was available and therefore the analysis was performed using one value per cell. This procedure had the effect of reducing the sensitivity of the F-test but was the only manner in which these data could be treated by analysis of variance. As no test for homogeniety of variance is available where there is only one reading per cell, homogeniety of variance had to be assumed. However, the assumption would appear to be valid as the arc sine tends to be distributed normally (14, pp. 164-165).

The development of performance curves. The purpose of this analysis was to describe the relationship between vision and performance on the various dials on the job-sample test. That a relationship existed was established by the analysis of variance. Curves, representing the relationship between performance and near point acuity, as measured by the Armed Foroes Vision Tester, for each dial, would provide a convenient means of establishing visual standards for the dials involved.

Analysis of the visual tasks involved in the job-sample test showed the dials were read at distances ranging from 16 to 24 inches. Therefore, the relationship between near visual acuity and job performance was the logical relationship to be studied. It was desired to use binocular acuity in the analysis; but as the Armed Forces Vision Tester contains only monocular acuity tests, for the purpose of this analysis best eye, near acuity scores were used as the best estimate of near binocular acuity available. Horowitz (12) reported that in general near binocular

acuity is better than monocular acuity in either eye. Therefore, the best eye near acuity score of a subject should approximate his binocular acuity. The average of the best eye near acuity scores made by each subject while wearing each of the lenses was used in the analysis. This resulted in five vision scores for each subject which are given in Appendix E.

The procedures followed for fitting the curves in general were the same as those outlined by Ezekiel (9) and by Croxton and Cowden (5). Curves representing the relationship between vision and performance on the time criterion were fitted to the data for each dial. A free-hand curve and one fitted by a mathematical function were developed for each dial. The curves fit by the mathematical function did not necessarily describe the nature of the relationship between near acuity and performance better than the free-hand curves, but were used as a convenient means of representing the data. In general, the mathematical curves departed very little from the free-hand curves.

Curves representing the relationship between performance on the accuracy criterion and near visual acuity scores were also developed. These curves were fitted by the free-hand method only.

The complete methodology used in developing the curves is included in Appendix F.

Results

Reliability. The reliability of performance, as measured by both the time criterion and the accuracy criterion, obtained for each dial and for the total test by correlating the odd against the even replications in the cells, is presented in Table 8.

Table 8

Reliability of Performance Scores

on the Job-sample Test

Dial No.	Reliability* (Time Criterion)	Reliability* (Accuracy Criterion)
1	.87	-.11
2	.92	.72
3	.84	.00
4	.94	-.15
5	.69	-.09
6	.95	.69
7	.98	.34
8	.90	.66
9	.91	.71
10	.92	.66
TOTAL TEST	.96	.59

*Corrected by Spearman-Brown Prophecy formula

Analyses of Variance. The analysis of variance of time performance was performed on the log log transformation of the time scores. The analysis is presented in Table 9.

TABLE 9

Analysis of Variance of Time Scores

Source of Variation	df	Sums of Squares	Mean Square	F-ratio
Between Subjects	9	3.9127	.4347	68.23*
Between levels of vision	4	14.3768	3.5942	89.82*
Between Dials	9	31.7613	3.5290	109.01*
Subjects x levels of vision	36	1.4404	.0400	6.28*
Subjects x dials	81	2.6222	.0324	5.08*
Dials x levels of vision	36	2.8773	.0799	4.48*
Subjects x dials x levels of vision	324	5.7790	.0178	2.80*
Within cells	4500	28.6761	.0064	
Total	4999	91.4458		

*Significant beyond the 1% level.

Seven hypotheses were tested in this analysis. The hypothesis of no difference between means for subjects, levels of vision, dials, and each of their first and second order interactions were evaluated.

The F-ratio for each of the main effects of subjects, levels of vision, and dials was significant beyond the 1% level. Therefore, for each main effect the hypothesis of no mean difference was rejected. In addition, the F-ratios for all the interactions of the main effects were significant beyond the 1% level of confidence.

The analysis of variance of accuracy scores was performed on the arc sine transformation of the percentage of correct readings in each cell of ten readings. The analysis is presented in Table 10.

TABLE 10

Analysis of Variance of Accuracy Score

Source of Variation	df	Sums of Squares	Mean Squares	F-ratio
Between Subjects	9	3069.20	341.03	7.02*
Between levels of vision	4	6162.80	1540.70	21.09*
Between Dials	9	12357.70	1373.08	14.54*
Subjects x levels of vision	36	2630.33	73.07	1.50**
Subjects x Dials	81	7647.38	94.41	1.94*
Dials x levels of vision	36	5705.04	158.47	3.26*
Subjects x dials x levels of vision	324	15749.37	48.61	
TOTAL	499	53321.82		

* Significant beyond 1% level
** Significant beyond 5% level

Six hypotheses were tested in this analysis. The hypotheses of no mean difference in accuracy for each of the main effects of subjects, levels of vision, and dials, and their three first-order interactions were evaluated. The F-ratios for each of the main effects were significant beyond the 1% level of confidence so the hypothesis of no mean difference was rejected for each. The F-ratios for the interaction of subjects and dials, and dials and levels of vision were also significant beyond the 1% level and the hypothesis of no mean difference was rejected in each case. The F-ratio for the interaction of subjects and levels of vision was significant at the 5% level and although not as significant as the other conditions, significant interaction between subjects and levels of vision was indicated.

<u>Time Performance Curves.</u> Mathematical curves, fitted to the data collected on the basis of the time criterion, were developed for each of the ten dials in the job-sample test. The mathematical curve that gave the best fit to the data for all dials was used.

The resulting curves for the easiest and most difficult dials are shown in Figure 1. Time scores in hundredths of minutes form the ordinate and Armed Forces Vision Tester Score, best eye, near acuity, form the successive abscissa.[3] The time curves developed for each of the ten dials are contained in Appendix F.

Accuracy Performance Curves. Free-hand curves, representing the curve of best fit to the data collected on the basis of the accuracy criterion as determined by eye were developed for each of the ten dials in the job-sample test. The resulting curves for the easiest and most difficult dials are shown in Figure 2. The percent of correct readings given form the ordinate and the successive abscissa are visual-acuity scores obtained on the Armed Forces Vision Tester.[4] The accuracy curves developed for each of the ten dials are contained in Appendix F.

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3. The corresponding Snellen acuity notation for each Armed Forces Vision Tester score is also given on the abscissa.

4. The corresponding Snellen acuity notation for each Armed Forces Vision Tester score is also given on the abscissa.

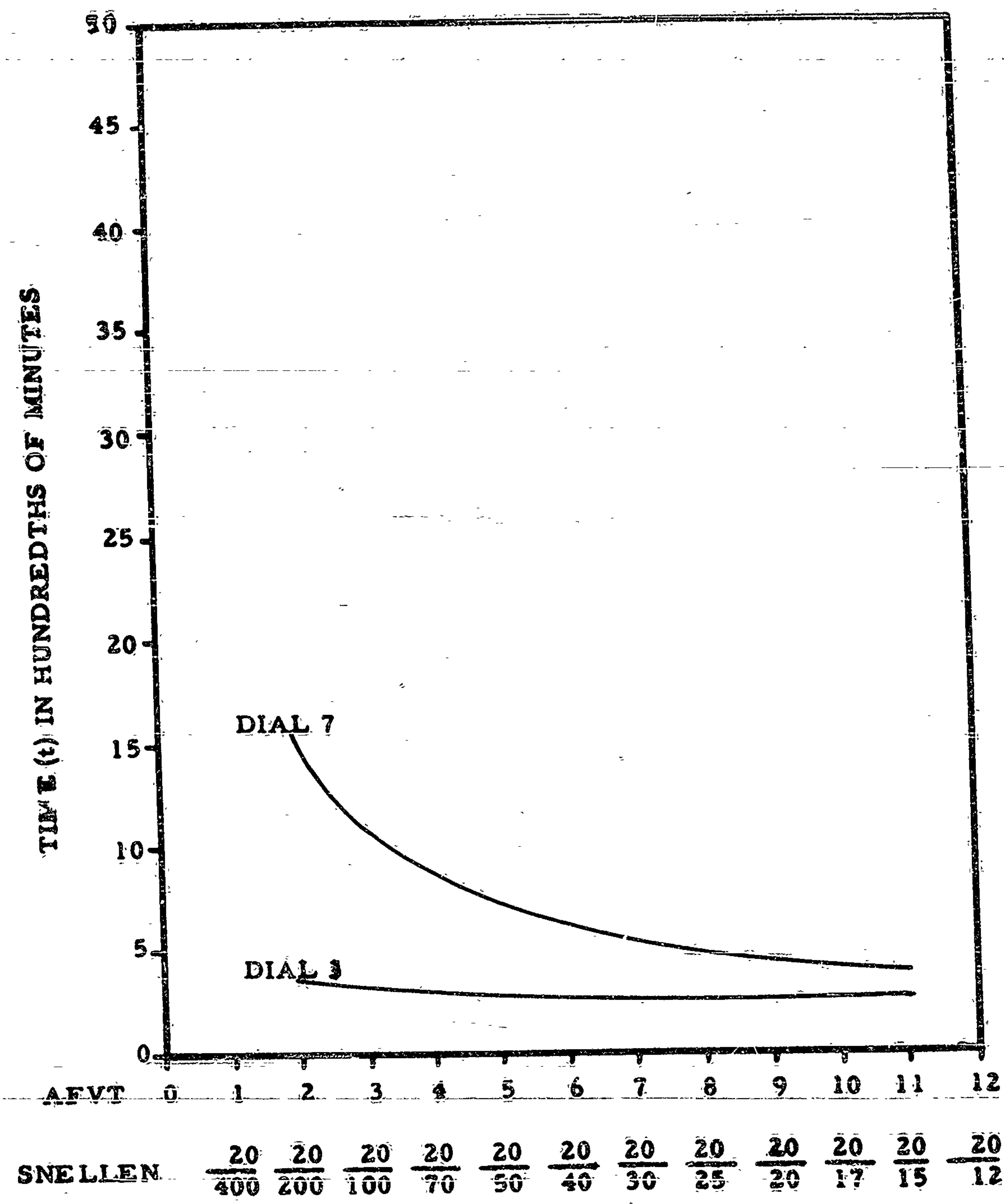

FIG. 1. COMPARISON OF RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIALS 3 (EASIEST) AND 7 (MOST DIFFICULT).

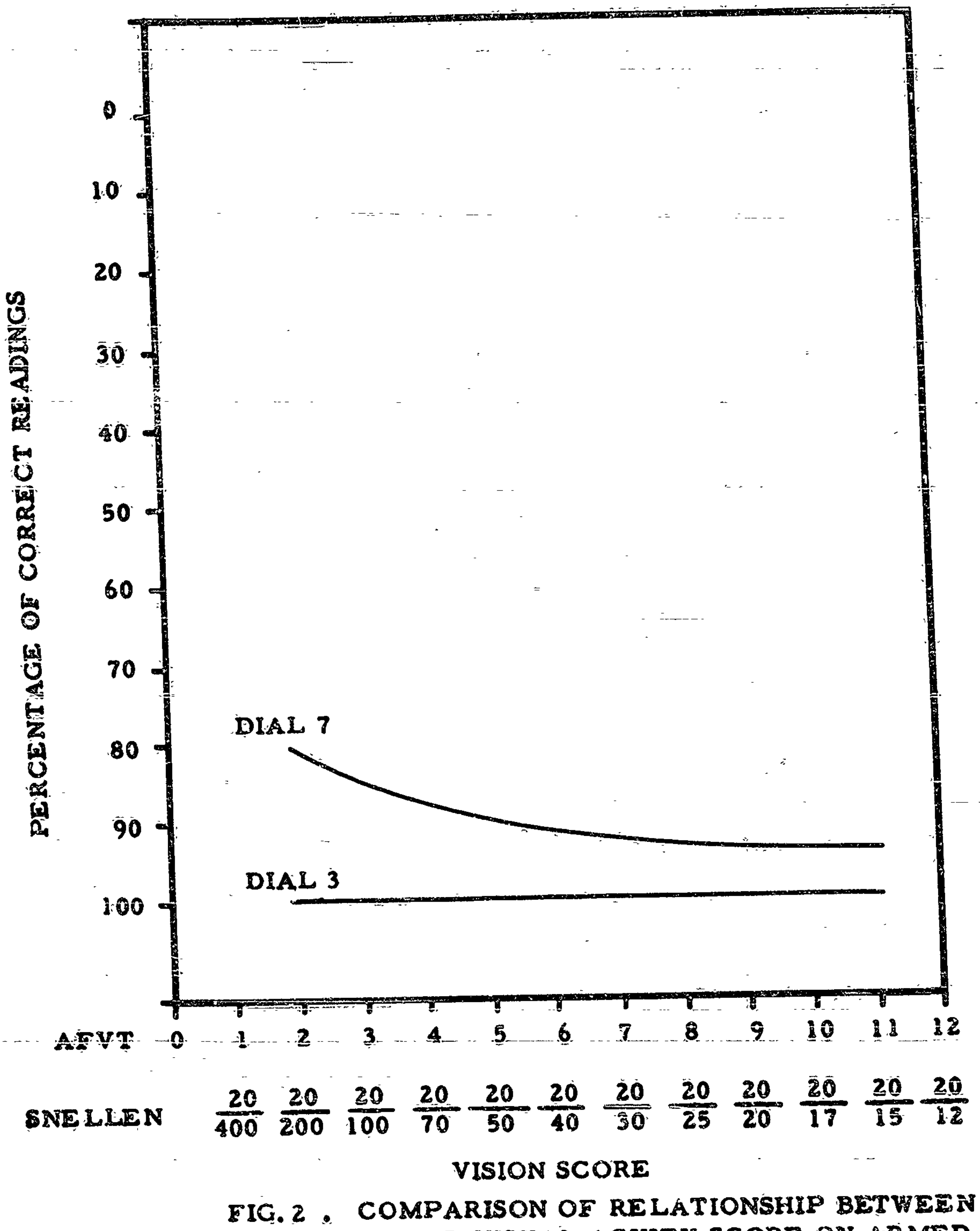

FIG. 2 . COMPARISON OF RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIALS 3 (EASIEST) AND 7 (MOST DIFFICULT).

Interpretation of Results

Reliability. The reliability of performance on the time criterion was of sufficient magnitude on all dials and on the total test to warrant the conclusion that on all dials the time scores obtained were a reliable measure of performance. Therefore, conclusions based upon performance, as measured by this criterion, were made with considerable assurance that if the experiment were repeated with the same subjects, or similar subjects, under the same conditions, similar results would be obtained.

The reliability of performance on the accuracy criterion was very low for certain dials. Inspection of the data revealed that few errors were made. Therefore, due to the nature of the data, the reliability coefficients necessarily were low. Although no conclusions were drawn concerning the reliability of performance, as measured by the accuracy criterion, inspection of the data revealed that performance, under a given condition, was highly consistent.

Analyses of Variance

Because all conditions in both analyses were the same, the F-ratios obtained for each of the main effects of dials, subjects, and levels of vision and each of their first and second order interactions were statistically significant in both analyses. Therefore, the hypothesis of no difference in mean performance was rejected for all conditions.

Of utmost importance in the evaluation of the methodology used in this experiment was the effect of levels of vision upon performance. As the hypothesis of no difference in mean performance at the five levels of vision was rejected, it was concluded that vision had a

real and significant effect upon performance. From this it was concluded that performance on the job-sample test, as measured by the criteria of performance, was related to vision; that as visual efficiency was reduced, performance on the dial reading task became poorer. Therefore, performance was a function of visual efficiency.

Of somewhat less, but still of major importance to the methodology investigated in this experiment, was the test of the differences between dials. As the hypothesis of no mean difference in performance on the ten dials was rejected, it was concluded there was a real and significant difference in performance on the different dials. From this conclusion it was inferred the visual task involved in reading the different dials differed in difficulty. Because there was a difference in performance on the different dials, it was concluded that visual standards would have to be developed for each dial separately; that because the different dials represented visual tasks differing in difficulty, visual standards developed on one dial could not be generalized to another dial. Therefore, on the basis of these results it was necessary to develop curves relating vision to performance for each dial separately.

The performance of the different subjects on the job-sample test differed significantly. The hypothesis of no difference in the mean performance of subjects was rejected. This result was expected as rarely do subjects perform alike on a complex task. The conclusion drawn from this result was that the performance of a subject on the job-sample test could not be predicted from the performance of another subject, but that the best prediction of any subject would be a prediction based on the group mean.

Each of the interactions of the main effects in the analysis was statistically significant. However, they were difficult to interpret, both statistically and in terms of their methodological significance. As they are of little importance in evaluating the methodological implications of the experiment, it need only be stated that the subjects reacted differently to the different levels of vision and to the different dials and that the function relating levels of vision to dials differed significantly for the different dials and levels of vision.

Performance Curves. Inspection of the performance curves on both the time criterion and error criterion showed that in general the curves followed the same trend. This indicated that good performance on one criterion was associated with good performance on the other. Likewise as performance decreased on the basis of one criterion it decreased in similar manner on the other. Furthermore, the point of vision at which the decrease in performance was accelerated was approximately the same on both sets of curves. It must be remembered that the time curves were curves fitted to the data using a mathematical function whereas the accuracy curves were free-hand curves fitted by eye. However, it was reasonable to assume that mathematical curves fitted to the accuracy data would not essentially change the shape of the curve. Therefore, it would appear to be feasible to set vision standards using only one set of curves, with the knowledge that a decrease in performance on the criterion on which the curve was developed would be accompanied by a similar decrease in the performance on the other criterion. Because of the high correlation between the two sets of curves the interpretation was based on time curves alone, as the time score was shown to be the

more reliable of the two measures of performance.

In interpretating the curves it must be stated that performance on the criterion should not be compared from one dial to another. The curve developed for each dial was a means of representing the relationship between near visual acuity and performance on that dial. The best performance to be expected on any one dial was that at so called normal, or 20/20 visual acuity (Armed Forces Vision Tester score of 9). Therefore, in evaluating performance on a dial, performance on the successively lower levels of visual acuity should be compared with that at 20/20 vision on that dial. Using this procedure, an estimate of the decrement in performance from that of 20/20 acuity due to lower visual acuity, can be made for each dial. On this basis visual standards could be set for each dial based on minimum acceptable standards of performance as determined by operating procedures.

It must be stated that standards set on the curves developed in this study cannot be generalized to other dials or to other visual tasks. These curves can be safely used only to set standards on the jobs involved, if the jobs are performed under the same conditions as the experiment. However, methodologically the curves developed assume considerable importance as a basis for setting visual standards.

Discussion of Results

<u>Methodological Implications.</u> The methodology evaluated in this study represented one approach to the problem of establishing visual standards. This approach differed from the methods in general use in the military services and in industry. Two aspects of this methodology radically departed from methodologies heretofore used:

(1) the use of a rigidly selected, highly motivated group of subjects, and (2) artificially altering the vision of the subjects so that the job performance of the same subjects at various levels of visual efficiency was measured. Of less but perhaps still of considerable importance to the problem of methodology of setting visual standards was the use of crossed cylinders to produce the artificial range of vision and the use of a job-sample test to measure job performance.

If the assumption were valid, that subjects in which low levels of visual acuity produced artificially by crossed cylinder lenses would perform in the same or in a similar manner as subjects who normally possess that low level of visual acuity when all other factors are held constant, the methodological implications of this approach assume great importance. For if this assumption is correct, an experiment in which extraneous factors are held constant, or at least controlled, can be used to determine the relationship between vision and job performance over the entire range of vision. This should have the effect of eliminating sources of error from experimental results and provide a more scientific basis upon which visual standards can be determined. In addition, the problem of obtaining subjects with certain visual characteristics is solved by the use of crossed cylinders.

Of great importance is the fact that curves which adequately described the relationship between the level of near point visual acuity and job performance on the two criteria of performance were developed for each of the ten dials. If either, or both criteria, time and accuracy, are valid measures of performance on this type of task, it can be inferred that curves, developed from experimental evidence

and based on one criterion of performance can be used to set visual standards. This means that a series of short experiments, conducted on a number of critical visual tasks, would result in a set of curves from which visual standards for a large number of jobs could be easily and quickly established.

It is of interest to note that one mathematical function adequately described the data collected on ten different dials. No conclusions are possible from this phenomenon but the writer suggests the possibility that mathematical functions might be developed to describe the relationship between the various visual functions and given types of visual tasks. The methodological implications of such a possibility assume considerable importance. However, the writer wishes to reiterate such a possibility is mere speculation, and evidence necessary to warrant a conclusion concerning this possibility is outside the realm of this study.

Possible Visual Standards. On the basis of the results of this study it was felt that certain conclusions concerning possible vision standards could be drawn. The results showed conclusively that vision, and more specifically, that near point visual acuity is related to performance on the dial reading tasks contained in the job-sample test used in this experiment. If the assumptions under which the study was conducted were tenable, expected performance on a certain dial at a given level of visual acuity could be predicted from the time performance curves developed. As it has been demonstrated that with each increase in visual acuity score there was an increase in performance, a minimum standard of performance set by the Navy on either of the two criteria evaluated could be located on the curve and

subjects whose visual acuity is at that point, or higher, could be expected to perform adequately the visual aspects of the task.

<u>Limitations of Results.</u> In evaluating the results of this study, there are a number of limiting conditions which must be taken into account before the results can be used to set visual standards.

<u>Criteria.</u> The criteria of performance that were used in this study were (1) time to read a dial, and (2) accuracy of the reading given. On a logical basis these criteria appear to be the best criteria available for evaluating performance on a job of the type used. No attempt was made to combine these criteria into a single criterion, although on the basis of the performance curves developed it was demonstrated they are highly correlated. Therefore, if either or both of these criteria can be used to measure job success, the results would appear to be valid. The final judgment as to the validity of the criteria would appear to rest with naval officials responsible for the success or failure of the Navy under battle conditions. The writer wishes to reiterate that the results can be valid only insofar as the criteria of performance were valid.

<u>Dials.</u> The results of this study can be generalized only insofar as the difficulty level of the dials used can be equated to other dials. This means that the factors of level and kind of illumination, brightness contrast, size and type of dial markings, frequency of response, whether the dial is moving or stationary, distance and angle from which the dial is read and perhaps other factors must be equated before these results can be generalized for the purpose of setting visual standards.

<u>Subjects.</u> Seldom, if ever, in the actual work situation will subjects comparable to those used in this study be available. It

would appear safe to assume that the level of intelligence and motivation of the experimental group were much higher than that which would be encountered in the work situation. Logically it would appear these factors would enhance job performance. However, it would also appear reasonable to assume that long experience in the work situation would tend to offset these advantages of the experimental group. However, these results can be used to set vision standards only insofar as the performance of the experimental group can be considered typical to that of operators who normally perform on the battle-stations studied.

Altered Vision. The basic assumption that subjects with altered vision will perform the same as, or similar to, subjects with the same vision normally, must be tenable if results obtained by the methods used are to be generalized. As stated before, the subject who normally has a low level of visual acuity might be able to use certain visual cues more efficiently because of long practice with poor vision. However, discussion concerning this problem between Dr. Henry Imus and Dr. Glen Fry of the Armed Forces Vision Committee and the research staff at Purdue University resulted in the conclusion that standards set on the basis of experimental evidence obtained on subjects with altered vision should approximate standards set on subjects normally having visual deficiencies. Furthermore, any error due to altered vision should result in more stringent standards which would be an error in a safe and, in most instances, desirable direction.

Experimental Conditions. The conditions of the experiment limit the degree to which generalization of the results can be made. The job-sample test was illuminated by daylight illumination and overhead lighting. Therefore, the illumination on the job-sample test

varied somewhat but was never lower than 20 footcandles. However, if the illumination had been lower than, or a good deal higher than, 20 footcandles, the results might have been different. Further experimentation designed to answer this question is recommended.

Also the distance at which the subjects were tested was that of the normal working position. The results of the experiment may have been different if the distance of the subjects from the visual task had been different. Further experimentation designed to solve this problem is indicated.

In addition to the above conditions, generalization of the results is limited by one other condition. In the job-sample test it was necessary to use stationary dials as test targets. In the work situation many dials are read while moving. Therefore, it would seem plausible to expect a difference in performance with the addition of this factor. A repetition of this or a similar experiment comparing performance on moving and stationary dials is recommended in order to determine the effect of this factor upon performance. If a difference in performance is found, separate curves would have to be developed for the moving dials.

Conclusions

On the basis of the evidence presented, certain conclusions concerning the methodological approach used in this study to determine vision standards appear warranted:

1. The relationship between vision and performance on a reliable job-sample test, using crossed cylinder oblique lenses to produce a range of vision, can be measured and evaluated.

2. The methodology used in this study provides a means whereby curves, representing the relationship between the different visual functions and job-performance can be developed for various visual tasks, from which visual standards can be rapidly and easily established.

3. Certain questions need to be answered before statements can be made concerning the extent to which performance curves developed for a given visual task can be generalized.

   (a) Would the results have been the same under all levels of illumination?

   (b) Would the results have been the same at different distances from the visual task?

On the basis of the experimental evidence further conclusions concerning the job-sample test used in this study appear warranted:

1. The reliability of the job-sample test on the time criterion was of sufficient magnitude to warrant conclusions on the basis of results obtained from its use.

2. Performance on the dial reading tasks used in this study was related to near point visual acuity as measured by the Armed Forces Vision Tester.

3. Inferences can be drawn concerning vision standards for four navy battlestation assignments.

PHASE IV

<u>Purpose:</u> The research conducted in Phase IV was specifically designed to extend the research conducted in Phase III. The research was conducted to investigate two of the questions limiting generalization of the results of Phase III.

The two major purposes of this study were:

(1) To determine the effect of illumination on the relationship between artificially altered vision and performance on a job-sample test.

(2) To determine the effect of distance from the work on the relationship between artificially altered vision and performance on a job-sample test.

Generally speaking, if by reducing illumination, the performance of subjects at all levels of vision was reduced uniformly, it could

be concluded the performance curves developed in Phase III would be the same shape as performance curves resulting from experiments conducted under other levels of illumination. However, if the curves for different levels of illumination were not the same shape, the level of illumination would have to be carefully considered when deriving visual standards.

The same reasoning holds for the effect of distance from the work on the performance curve. If by increasing the distance from the work the performance of subjects at all levels of vision was reduced uniformly, then it could be concluded the performance curves developed in Phase III would be the same shape as performance curves resulting from experiments conducted at different distances from the visual task. And it follows that if the curves were the same shape, then the visual standards derived would probably be the same regardless of the distance from the dials the experiment had been conducted. However, if the curves obtained at different distances were not parallel, the effect of distance from the job on performance would have to be carefully considered when deriving visual standards.

The Job-Sample-Test: A job-sample-test of the same type used previously was developed for this experiment. The job-sample test was developed using the equipment previously used in Phase I (See page 3). The apparatus was mounted in a vertical position on a table. Only one dial was used and it was 44 inches above the floor, which placed it directly in the line of sight of a subject seated on a test chair. The visual task consisted of two concentric dials, one within the other. The subjects' task was to read the value on the outer dial that was indicated by a pointer on the inner dial. The pointer was always set on the markings on the dial.

A panel was built 6" in front of the equipment which completely shielded it from the subjects' view. Directly in front of the appropriate dial, and on a line with the subjects' vision, a spring actuated shutter was installed in the panel. The shutter was 6" wide by 5" high and when opened presented the subject a view of the complete dial. The shutter was opened from a remote position by depressing a key which actuated an electro-magnetic catch which in turn allowed a spring to open the shutter. The subject would then report the reading on the dial. The shutter was closed manually, the dial reset, and the cycle was repeated.

The surface of the dial was illuminated by six incandescent bulbs placed between the panel and the equipment.

The five levels of illumination were obtained by lighting the appropriate bulb, or bulbs. Both the brightness of the dial and the illumination on the dial were measured using the MacBeth Illuminometer. Brightness refers to the amount of light reflected from the dial to the subject, and illumination refers to the amount of light falling on the dial from the source. Since the dial was not of uniform brightness, four readings were taken and averaged as representing the brightness value. The readings were taken in the top, bottom, left, and right portion of the dial and then averaged which gave an approximate value. The uneven brightness probably caused some settings to be easier to read than others; however, the settings were chosen by random numbers and all subjects had an equal opportunity to perform on all portions of the dial. Table 11 gives the approximate values of the illumination and brightness of the dial for the five levels of illumination.

TABLE 11

Illumination and Brightness of dial values in foot-candles under five experimental conditions*

Experimental Condition	Level Of Illumination	Brightness Of Dial
1	563.89	78.75
2	105.26	8.90
3	34.89	3.24
4	15.13	1.60
5	0.29	0.03

* Because of the unreliability of the measuring instrument these values are the average of three measurements. These averages should closely approximate the true values

The three distances used in the experiment were 12", 20", and 30" from the dial to the subjects' eyes. These distances were held constant by means of a chin rest attached to the experimental chair on which the subject was seated. In order to obtain a desired distance, the experimenter could move the chair in relation to the dial and fix it at any of the three distances by means of a wooden jig placed on the floor. This allowed the distance to be changed accurately and quickly.

Two experimenters were required to operate the apparatus. The duties of the experimenter (E-1) were to (1) give the subject oral instructions, (2) administer practice runs, (3) manually close the shutter, and (4) set the dial at the appropriate readings. The duties of the other experimenter (E-2) were to (1) give the command "ready" to the subject and then depress the key which opened the shutter, (2) time the subject with a stop watch from the time the key was depressed until the subject responded, (3) record the time, and (4) record the response. Assuming the subject was ready to be tested and the levels of illumination and distance were appropriate, the sequence of operation was as follows: (1) with the shutter closed E-1 set the dials at the appropriate setting, (2) E-2 gave the

command "ready", then depressed the key which opened the shutter and started a stop watch. (4) E-1 closed the shutter while E-2 recorded the time and the response. (5) E-1 set the dials at the appropriate reading and the entire cycle was repeated

If the subject could not respond to a setting after 50/100ths of a minute, the shutter was closed and E-2 recorded a time of 50/100ths of a minute and "no response" for the reading which was scored as an error. Ten replications made up a cell. A new set of conditions would then be established, and ten readings taken under these conditions, etc.

Criteria of Performance. The two measures of performance, time and accuracy, that were used in Phases I, II, and III were also used in this experiment. (See page 4).

Methods of Procedure

Subjects. The ten subjects used in Phase III were used in this experiment. The spectacles worn by the subjects during Phase III were also worn during this experiment. (See page 18.)

Method of altering Vision. Vision was altered in this experiment in the same manner as Phase III. Five levels of altered vision were obtained using crossed cylinder clip-on lenses. (See page 20).

Design of the Experiment. The experiment was designed and conducted so that the results could be analyzed by means of analysis of variance using a factorial design. There were 10 subjects, 5 levels of illumination, 3 distances, and 5 levels of vision which gave a total of 750 cells. There were 10 readings in each cell. Each subject performed on all combinations of vision, illumination, and distance.

A test period for a subject consisted of performing on the five

levels of illumination and three distances at a given level of vision. Thus, during a test period, the data for 15 cells were obtained at one level of vision. It took 5 test periods (i.e. performance at 5 levels of vision) for a subject to complete the experiment. The order of the levels of vision was chosen from a table of random squares in Fisher and Yates (10), and is contained in Appendix G.

Within a given subjects' "by levels of vision" classification, there were fifteen cells composed of 5 levels of illumination and 3 distances which were randomly ordered. This was accomplished by making up a deck of 15 cards with each card representing one of the possible combinations of 5 levels of illumination and 3 distances or, in other words, each card represented one of the fifteen cells. This deck was shuffled thoroughly and the fifteen cards were dealt in sequence to determine the order of performance on the fifteen cells. This was repeated for each of the 50 combinations of 10 subjects and 5 levels of vision.

The settings for the dial were chosen from a table of random numbers; only even numbers were chosen. A total of 15,000 readings was necessary; 7,500 were used as the actual setting to which the inner dial pointed and the other 7,500 were used as a setting read only by the experimenter at the outer dial under the hairline. This served to randomly position the outer dial and prevent the subject from establishing a frame of reference about the inner dial.

<u>Administration of the Experiment:</u> The following describes the operation of the experiment in terms of the chronological activities of a subject.

(1) The subject entered the test room and was given his glasses and the appropriate clip-on lenses for his test

period. If this was the subject's first test period, he was given an introductory talk explaining the experiment. All subjects had participated in Phase III where they performed similar tasks.

(2) The subject's vision was measured on the Armed Forces Vision Tester and the Bausch and Lomb Orthorater. Vision was measured on both instruments according to the prescribed methods and procedures. (32,33)

(3) The subject was seated in the test chair at the appropriate distance and with the appropriate level of illumination on the dial. If this was the subject's first test period, he was given an extensive training period on reading the dial and several trial runs to become accustomed to the testing procedure. If the subject had participated previously, he was given a few trial runs to become accustomed to the conditions.

(4) The sequence of ten presentations was completed for that set of conditions.

(5) The chair was moved and the illumination level was changed for the next set of conditions.

(6) The subject was given a few warm up trials to get adjusted to the different level of illumination and distance.

(7) The sequence of ten readings was completed for this set of readings.

(8) This operation was continued until the sequence of ten readings for all combinations of distance and illumination for a given visual level had been administered. This gave a total of fifteen cells (5 levels of illumination x 3 distances) to be administered at one level of vision which took about an hour and twenty minutes. Generally speaking, the subject had a day of rest between performance on each visual level group of fifteen cells.

Analysis of Data

Reliability: The purpose of this step was to investigate the nature of the test itself and determine if it was a reliable estimate of job performance. The reliability of the time criterion was calculated by correlating the time scores on the odd replications with the time scores on the even replications within a cell. The obtained reliability was stepped up by using the Spearman-Brown Prophecy

formula (11). The reliability of the time criterion was .96.

The reliability of the accuracy criterion was estimated in the same way as the time criterion by correlating the performance on the odd replications with the performance on the even replications within each cell. If the response was correct, it was assigned a score of 1; if the response was incorrect, it was assigned a score of 0. The stepped-up reliability using the Spearman-Brown Prophecy formula was .85.

<u>Analysis of Variance. Time Criterion:</u> The purpose of this step was to determine if subjects, levels of vision, distance, and/or illumination significantly affected performance as measured by the time criterion. The nature of the interactions were also of importance since they were an indication of whether or not the curves were the same shape.

Before the analysis of variance could be performed it was necessary to analyze the data in order to determine if the assumption of homogeniety of variance could be met. The cell means were plotted against cell variances and on the basis of visual inspection a marked relationship seemed to exist. Bartlett's Test (7, p.196) for homogeniety of variance was made on the raw data and on the basis of this test, the hypothesis of homogeniety was rejected. This indicated that the raw data would have to be transformed to another scale before the assumption of analysis of variance could be met.

Several transformations were made, but the assumption could not be completely met by any of them. The log log transformation most nearly met the assumption and was used in the analysis. A description of the transformations and the Bartlett tests is in Appendix D. The result of failing to meet all of the assumptions

was to overestimate the level of significance (3,17). For this reason the 1% level of significance should perhaps be considered as being significant at the 5% level as a conservative estimate.

Analysis of Variance, Accuracy Criterion: The purpose of this step was to determine if subjects, levels of vision, distance, and/or illumination significantly affected performance as measured by the error criterion. The nature of the interactions were also of importance since they gave an indication of whether or not the performance curves were the same shape.

In this analysis there was only one score per cell which was the proportion of the 10 responses which was correct. It was necessary to convert this proportion by an arc sine transformation (23, pp.488-492), in order to perform an analysis of variance.

Development of Performance Curves: The purpose of this step was to describe the relationship between performance and vision under the various levels of illumination and distances. The fact that some kind of relationship existed had been established previously in the analysis of variance. These curves, representing the relationship between performance and near point acuity as measured by the Armed Forces Vision Tester, would provide a means of establishing visual standards for the dial involved. As stated previously, one of the major purposes of this study was to determine the nature of the relationship between these curves, particularly as to whether or not the curves were the same shape. The measure of vision used in developing the performance curves was the same as used previously in Phase III; best eye, near acuity score on the Armed Forces Vision Tester (See page 25). Further the procedures followed for fitting the

curves were the same as those used in Phase III (See page 26). Fifteen curves were developed for each measure of performance, one for each of the 15 combinations of 3 distances and 5 levels of illumination.

Results

The analysis of variance of the time scores is shown in Table 12. The significance levels should be interpreted with care since all of the assumptions of analysis of variance could not be met.

TABLE 12

Analysis of Variance of Time Scores

Source	df	Sum of Squares	Mean Square	F-ratio
Subjects	9	7.5822	0.8425	156.02*
Levels of Vision	4	27.8834	6.9708	49.16*
Distance	2	13.2851	6.6426	265.70*
Illumination	4	7.7194	1.9298	119.86*
Sub. x Lev. of V.	36	5.1056	0.1418	26.26*
Sub. x Dist.	18	0.4501	0.0250	4.63*
Sub. x Illum.	36	0.5807	0.0161	2.98*
Levels x Dist.	8	6.6278	0.8285	50.83*
Levels x Illum.	16	3.0282	0.1893	16.90*
Dist. x Illum.	8	1.0544	0.1318	11.98*
Sub. x Lev. of V. x Distance	72	1.1740	0.0163	3.02*
Sub. x Lev. of V. x Illumination	144	1.6180	0.0112	2.07*
Sub. x Distance x Illumination	72	0.7912	0.0110	2.04*
Sub. x Lev. of V. x Dist. x Illum.	288	3.5323	0.0122	2.26*
Lev. x Distance x Illumination	32	0.9448	0.0295	2.42*
Within Cells	6750	36.2504	0.0054	
TOTAL	7499	117.6276		

*Significant beyond 1% level

The analysis of variance of the accuracy scores is shown in Table 13.

TABLE 13

Analysis of Variance of Accuracy Scores

Source	df	Sum of Squares	Mean Square	F-ratio
Subjects	9	11,177.79	1,241.92	10.13*
Levels of Vision	4	68,523.92	17,130.98	47.74*
Distance	2	59,940.44	29,970.22	125.99*
Illumination	4	14,417.81	3,604.45	35.66*
Sub. x Lev. of V.	36	12,917.65	358.82	2.93*
Sub. x Distance	18	4,281.79	237.88	1.94**
Sub. x Illumination	36	3,638.90	101.08	0.82
Lev. of V. x Dist.	8	28,168.91	3,521.11	25.20*
Lev. of V. x Illum.	16	10,809.39	675.59	5.72*
Dist. x Illum.	8	6,643.00	830.38	5.37*
Sub. x Lev. of V. x Distance	72	10,058.31	139.70	1.14
Sub. x Lev. of V. x Illumination	144	17,005.16	118.09	0.96
Sub. x Distance x Illumination	72	11,133.30	154.63	1.26
Lev. of V. x Dist. x Illumination	32	7,402.72	231.34	1.89*
Sub. x Lev. of V. x Dist. x Illum.	288	35,304.73	122.59	
TOTAL	749	301,423.32		

* Significant beyond 1% level
** Significant beyond 5% level

Curves showing the relationship between job performance and near visual acuity are contained in Figures 3 through 18. Figures 3, 4, 5, 6 and 7 show the relationship between time performance and near visual acuity for all distances at each level of illumination. Figures 8, 9, and 10 show the same relationship for all levels of illumination at each distance. Figures 11, 12, 13, 14 and 15 show the relationship between between accuracy of performamce and near visual acuity for all distances at each level of illumination. Figures 16, 17, and 18 show the same relationship for all levels of illumination at each distance.

Analyses of Variance. The results of the analysis of variance of the time criterion showed that all main effects and all interactions were significant at better than the 1% level of confidence. Taking into consideration the fact that the assumption of homogeniety of variance was not met, the F-ratios still appear considerably larger than those required if the assumptions had been met. Since the

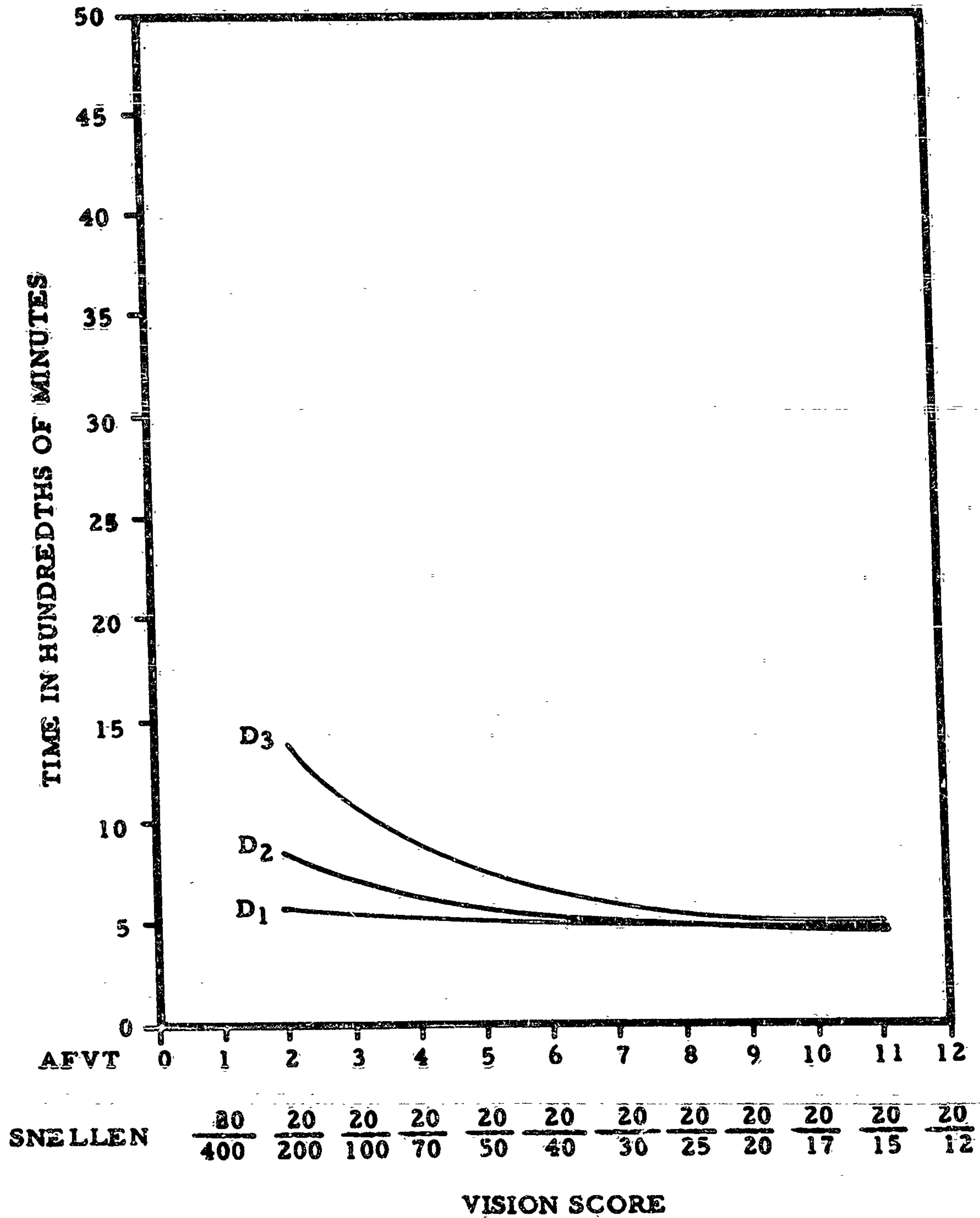

FIG. 3 . COMPARISON OF RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT ILLUMINATION LEVEL 1.

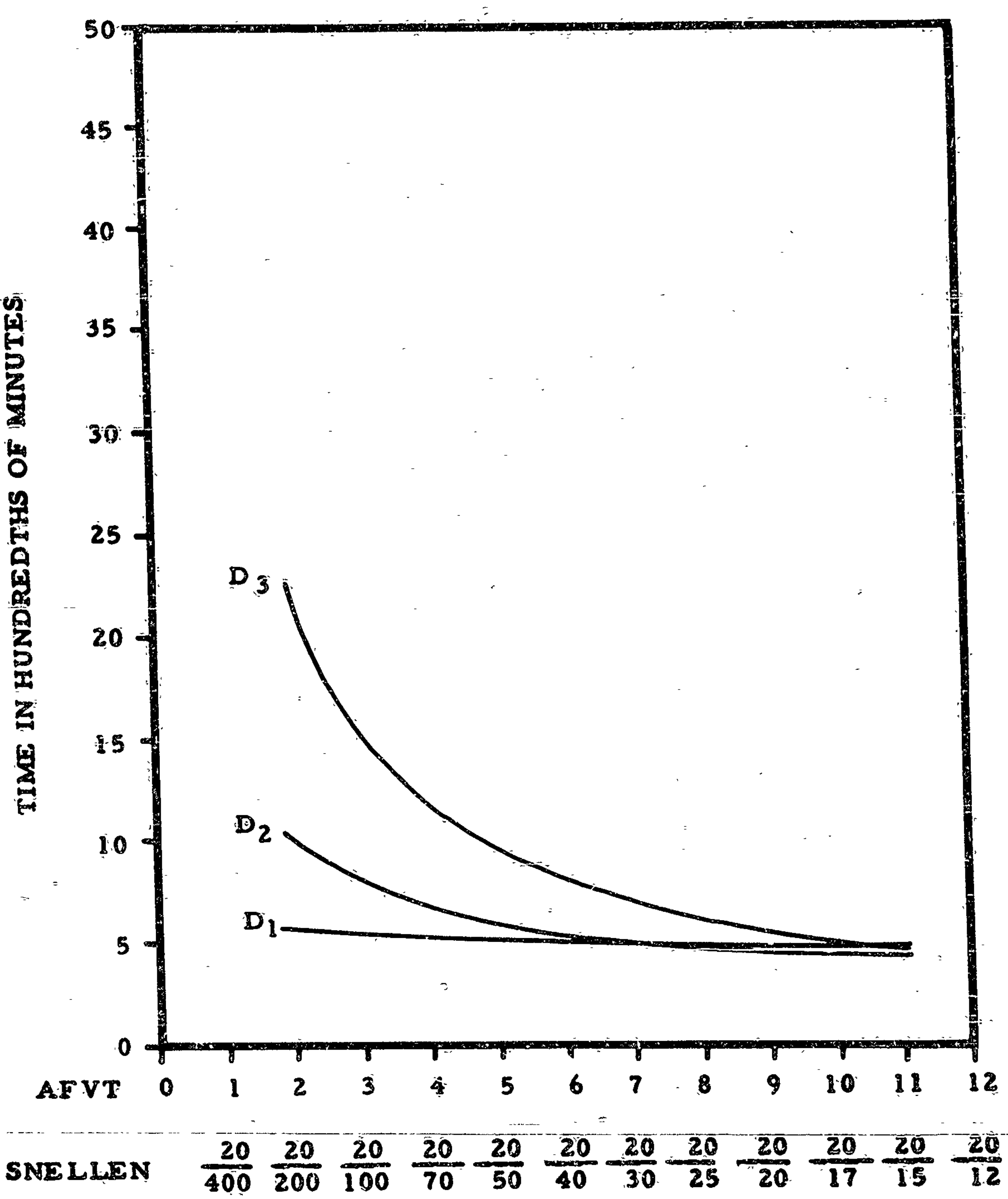

FIG. 4 . COMPARISON OF RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT ILLUMINATION LEVEL 2.

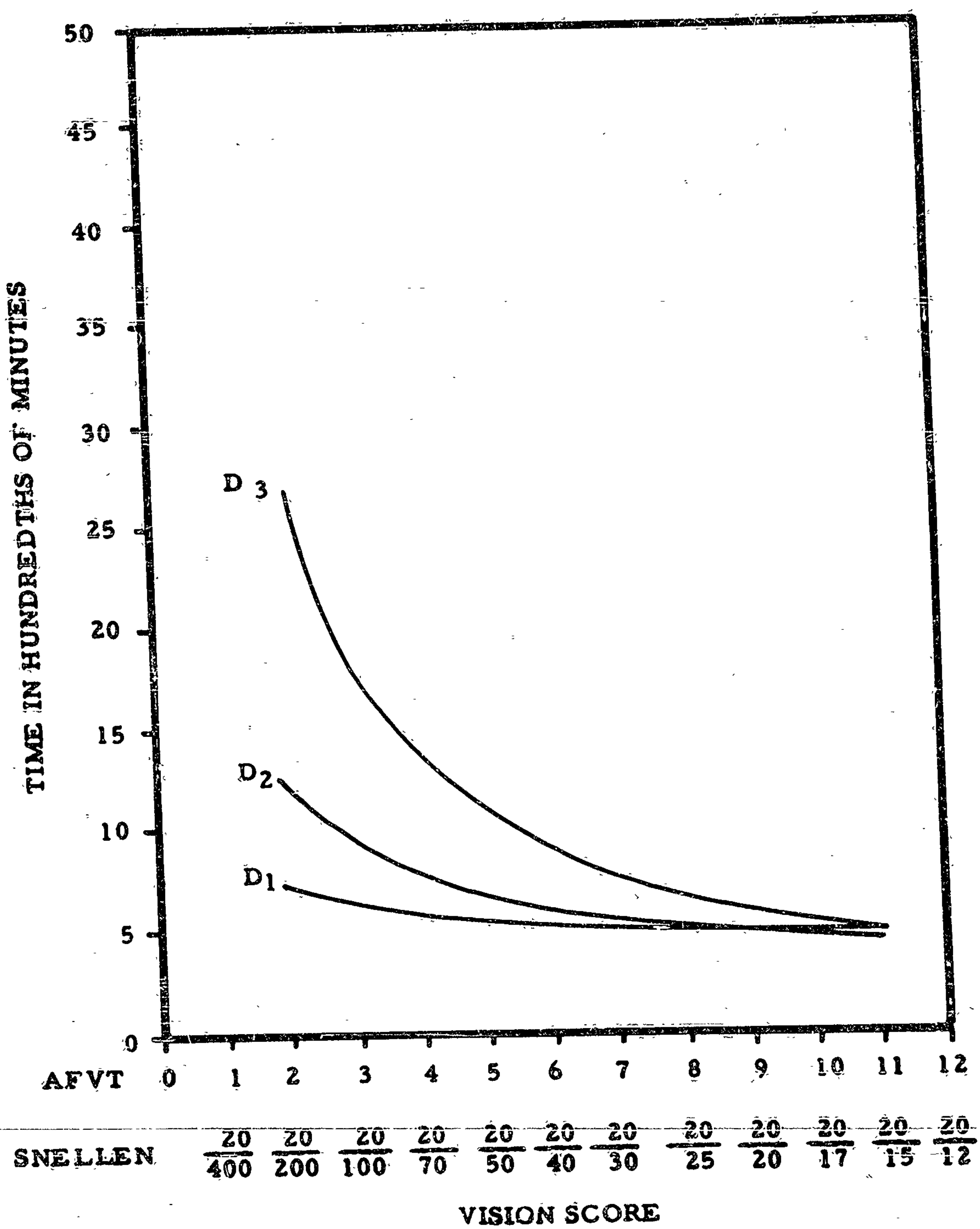

FIG. 5 . COMPARISON OF RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT ILLUMINATION LEVEL 3.

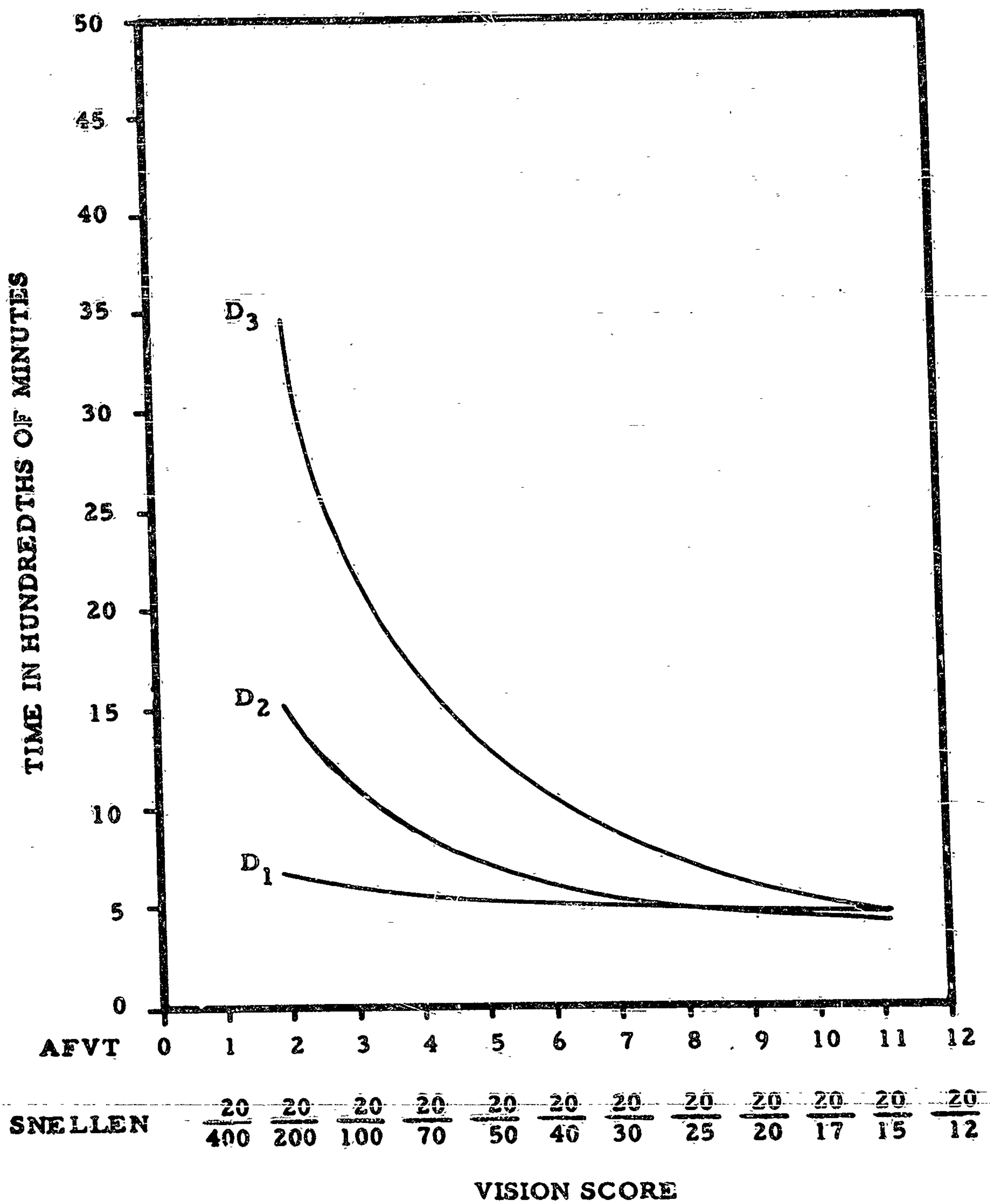

FIG. 6 . COMPARISON OF RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT ILLUMINATION LEVEL 4.

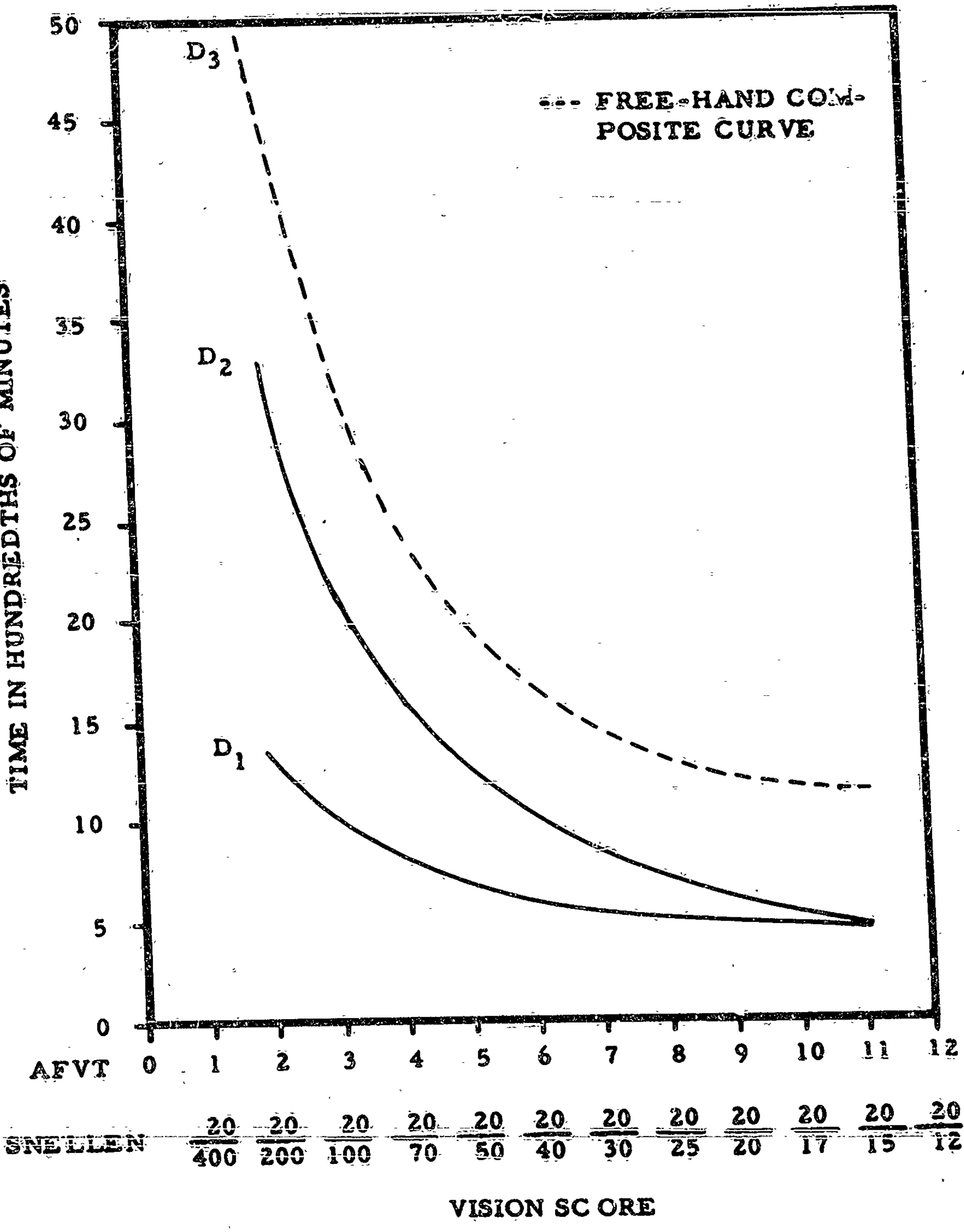

FIG. 7. COMPARISON OF RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT ILLUMINATION LEVEL 5.

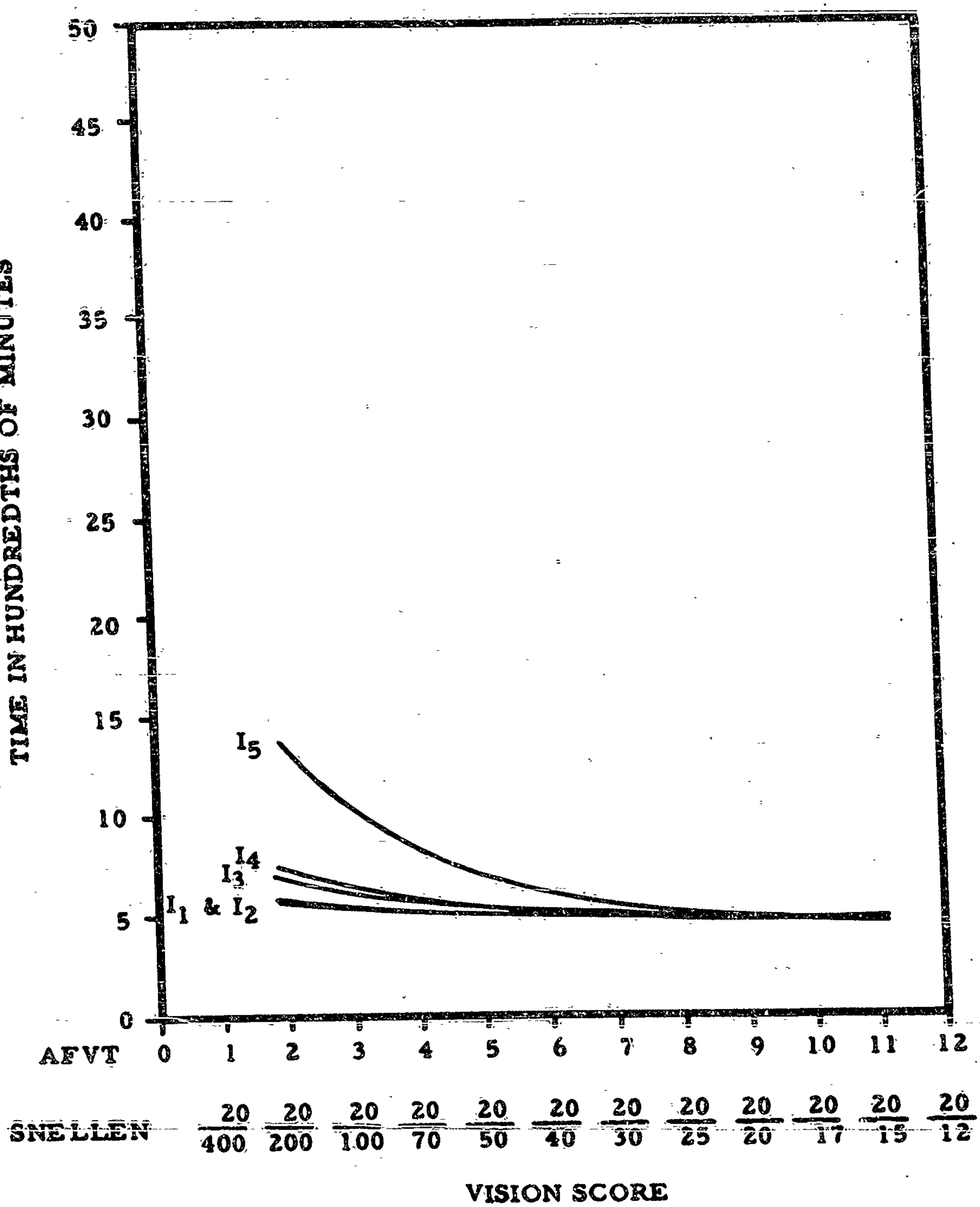

FIG. 8. COMPARISON OF RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL LEVELS OF ILLUMINATION AT DISTANCE 1.

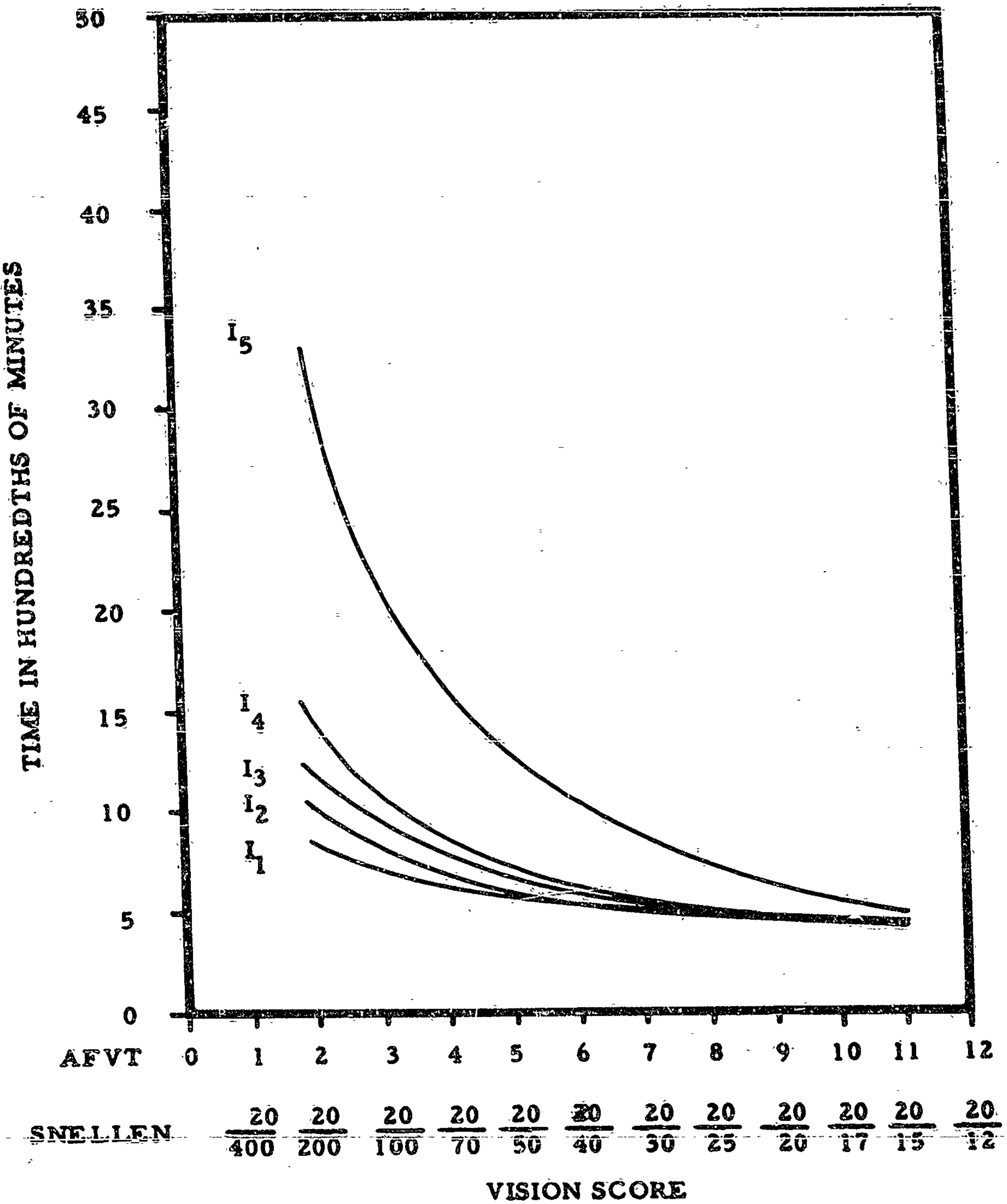

FIG. 9 . COMPARISON OF RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL LEVELS OF ILLUMINATION AT DISTANCE 2.

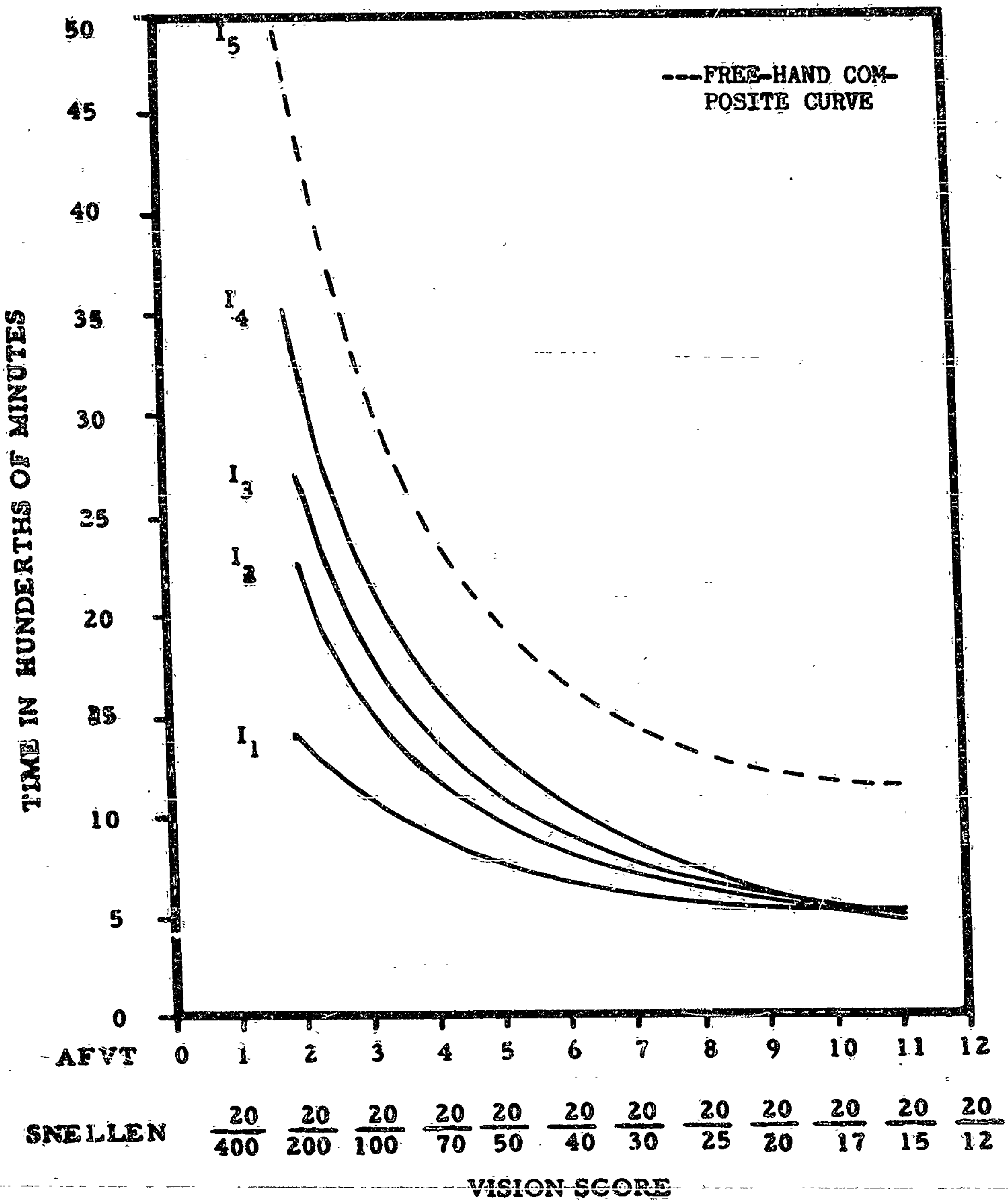

FIG. 10. COMPARISON OF RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL LEVELS OF ILLUMINATION AT DISTANCE 3.

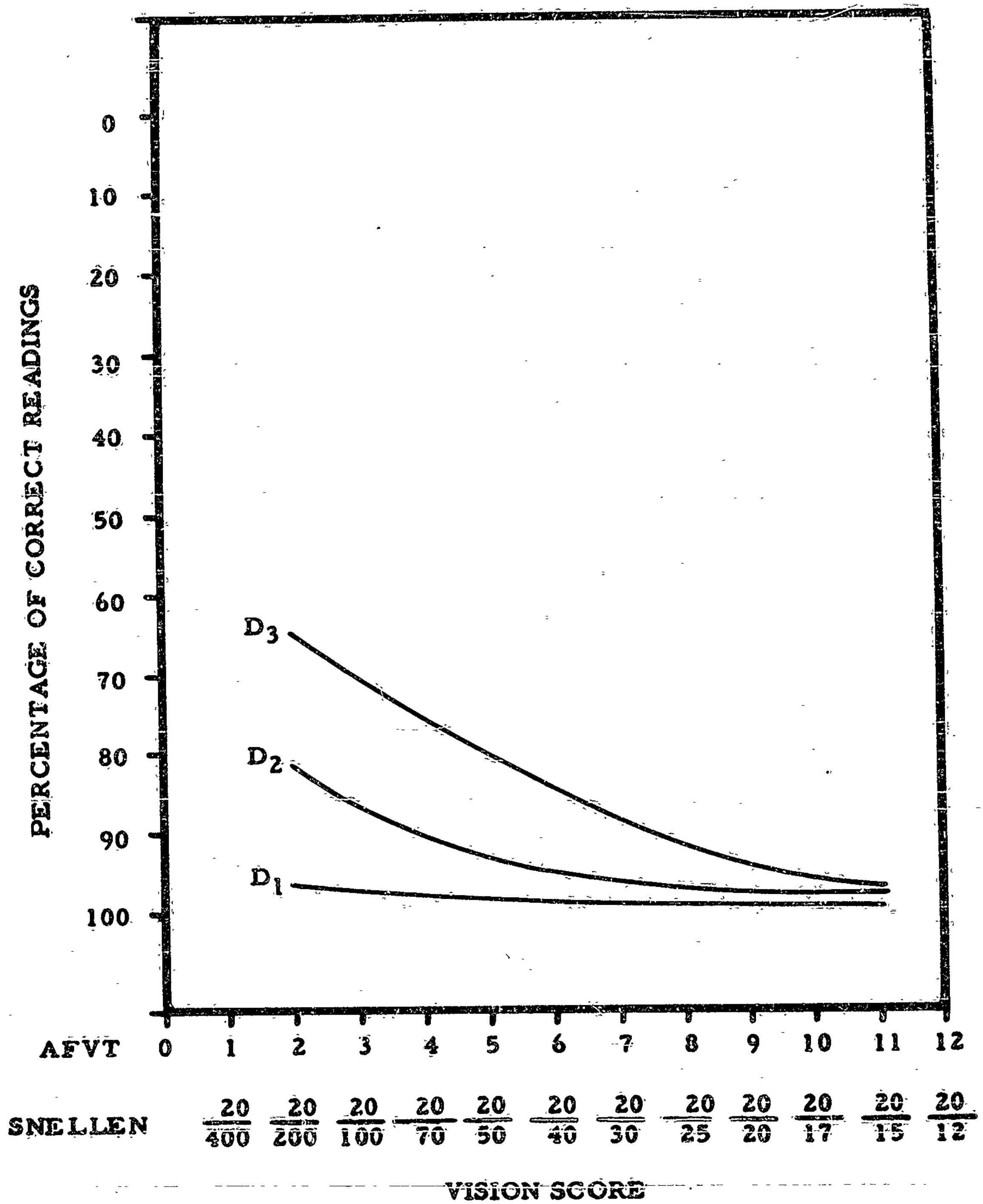

FIG. 11. COMPARISON OF RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT LEVEL OF ILLUMINATION 1.

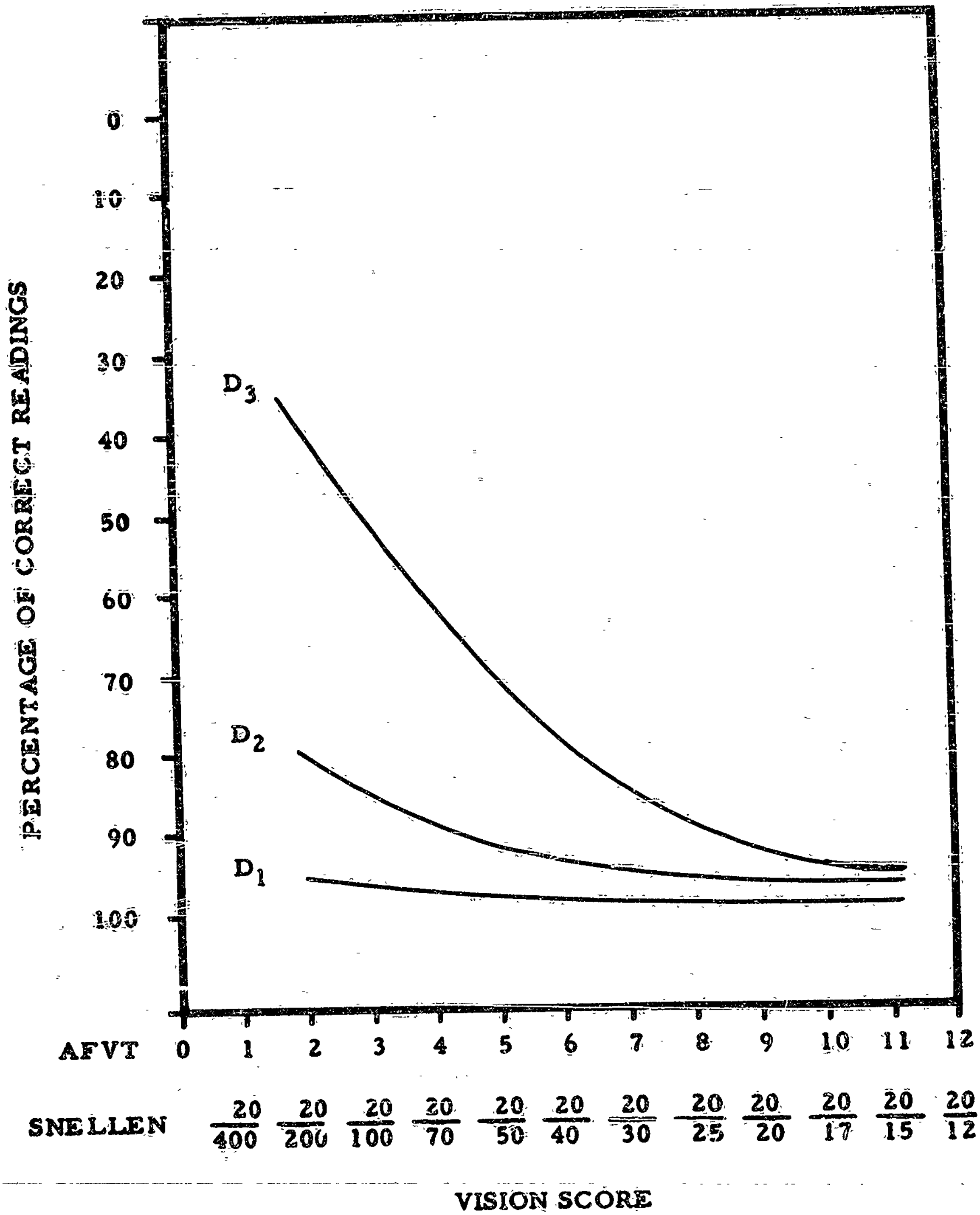

FIG. 12. COMPARISON OF RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT LEVEL OF ILLUMINATION 2.

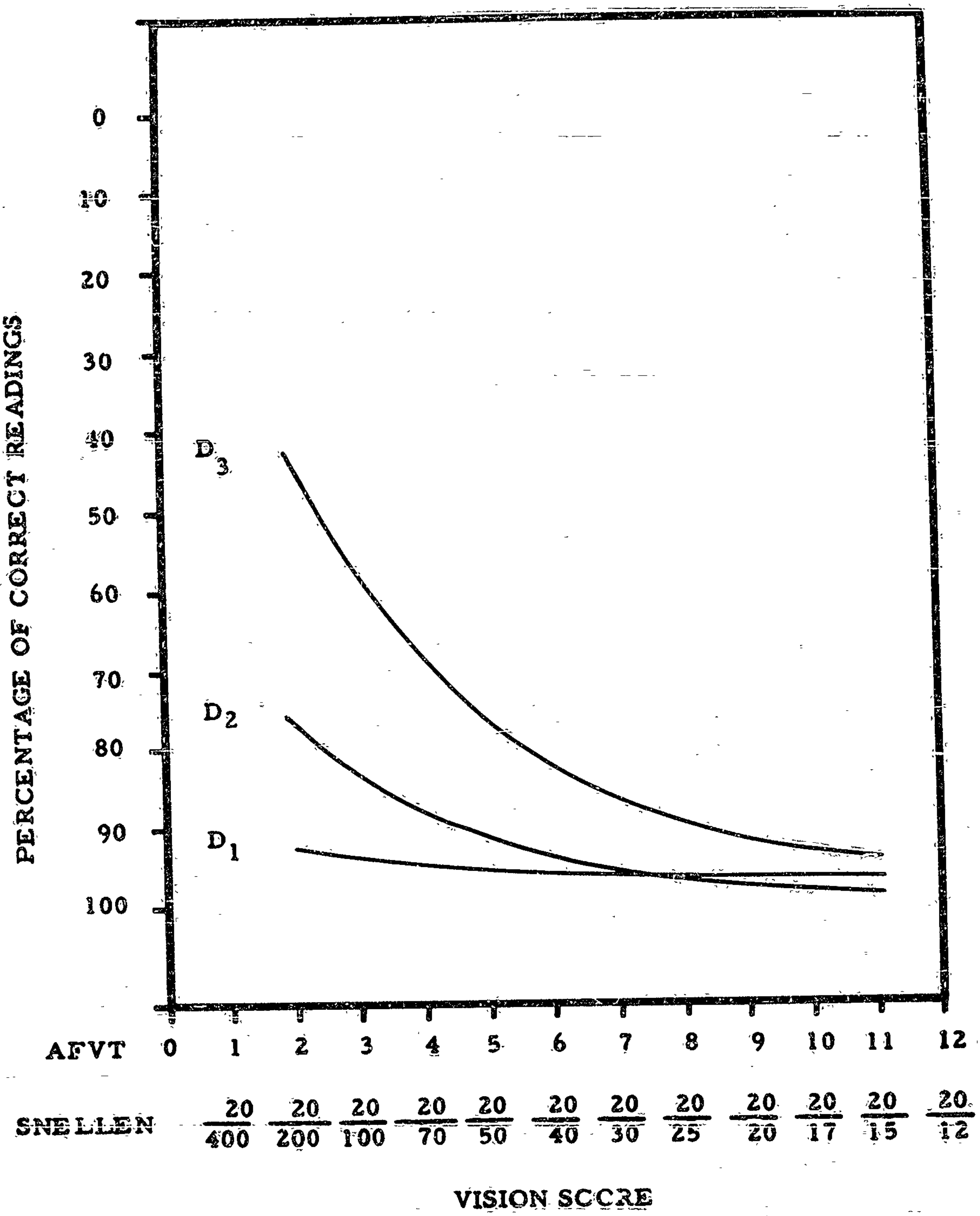

FIG. 13. COMPARISON OF RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT LEVEL OF ILLUMINATION 3.

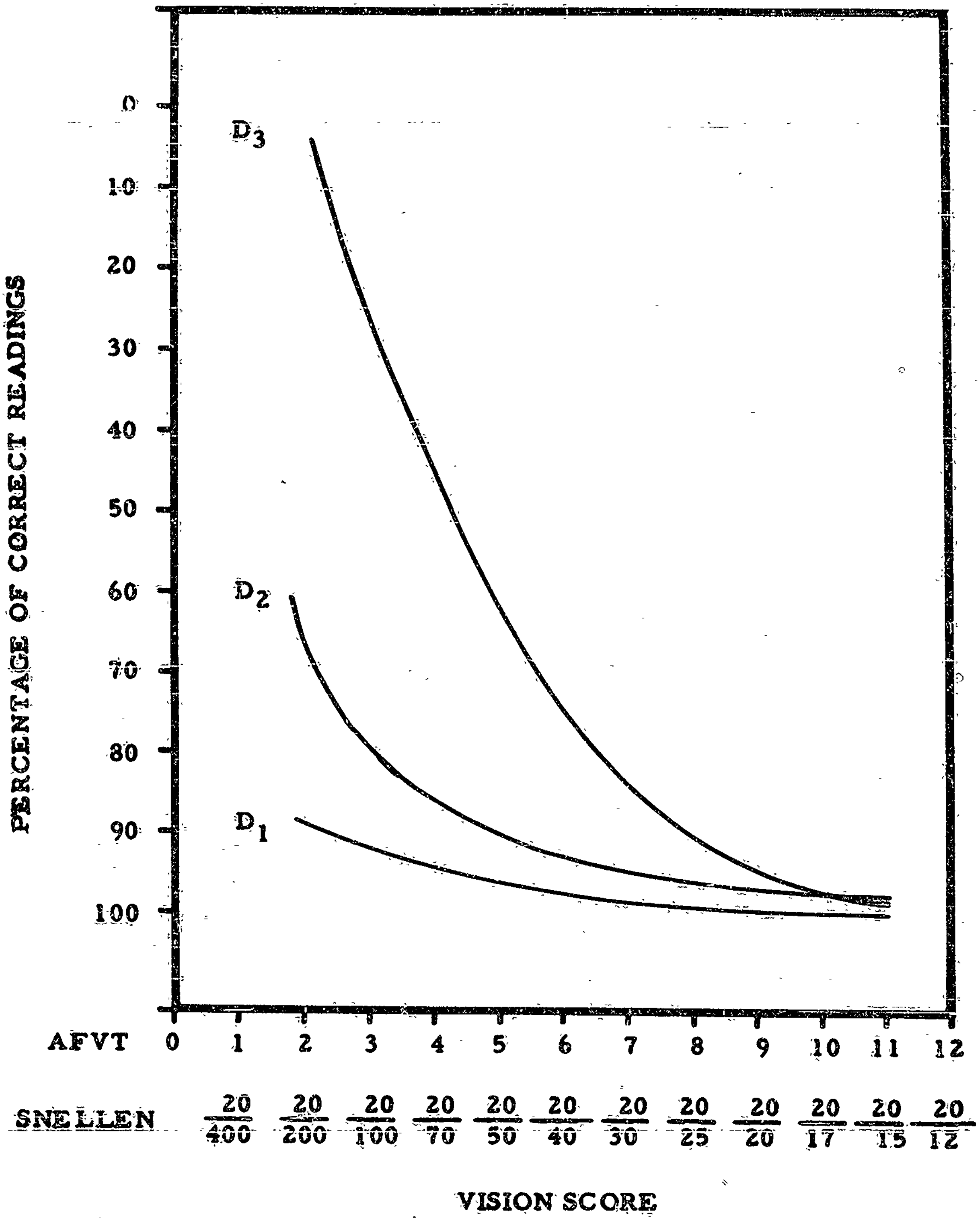

FIG. 14. COMPARISON OF RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT LEVEL OF ILLUMINATION 4.

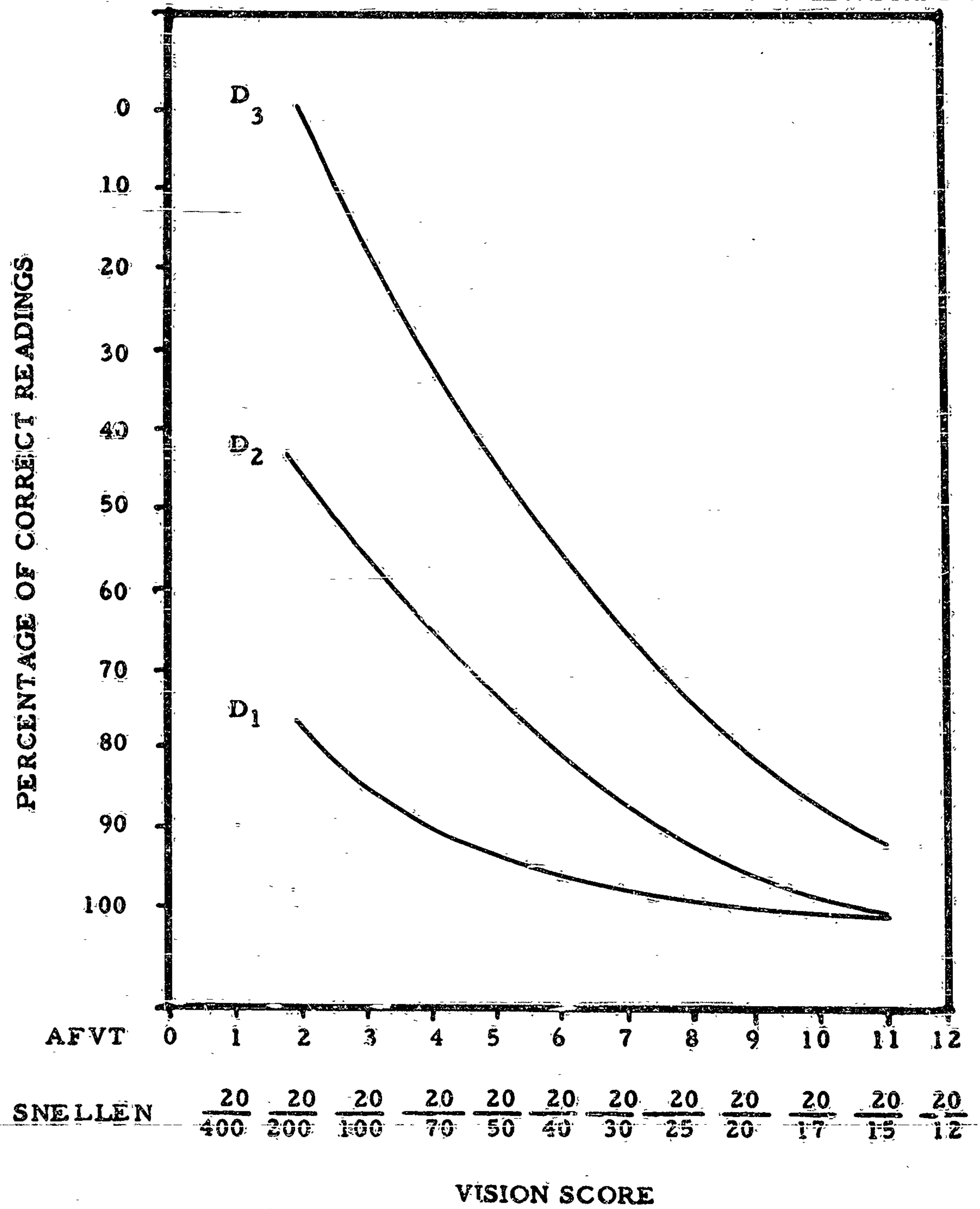

FIG. 15. COMPARISON OF RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL DISTANCES AT LEVEL OF ILLUMINATION 5.

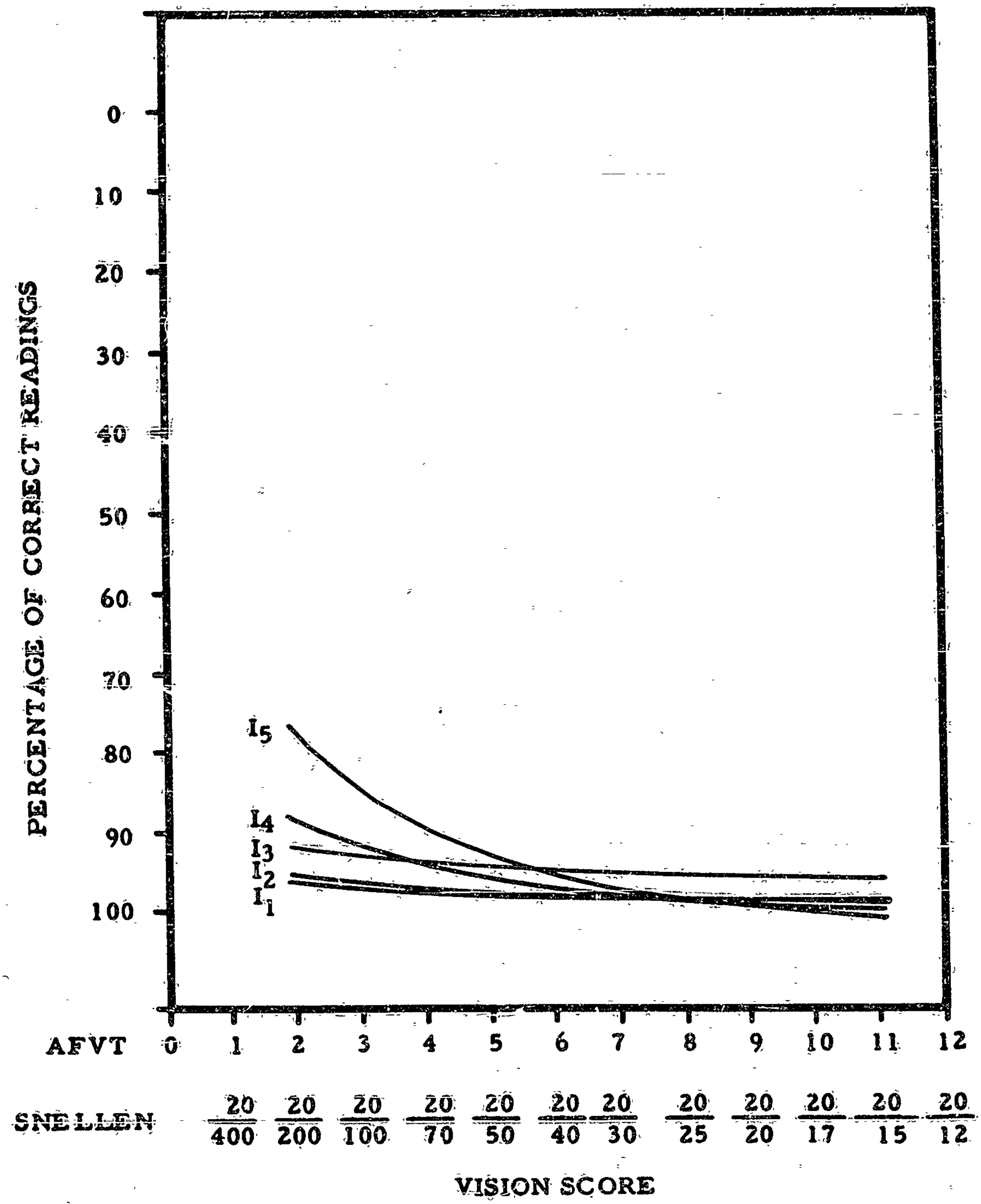

FIG. 16. COMPARISON OF RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL LEVELS OF ILLUMINATION AT DISTANCE 1.

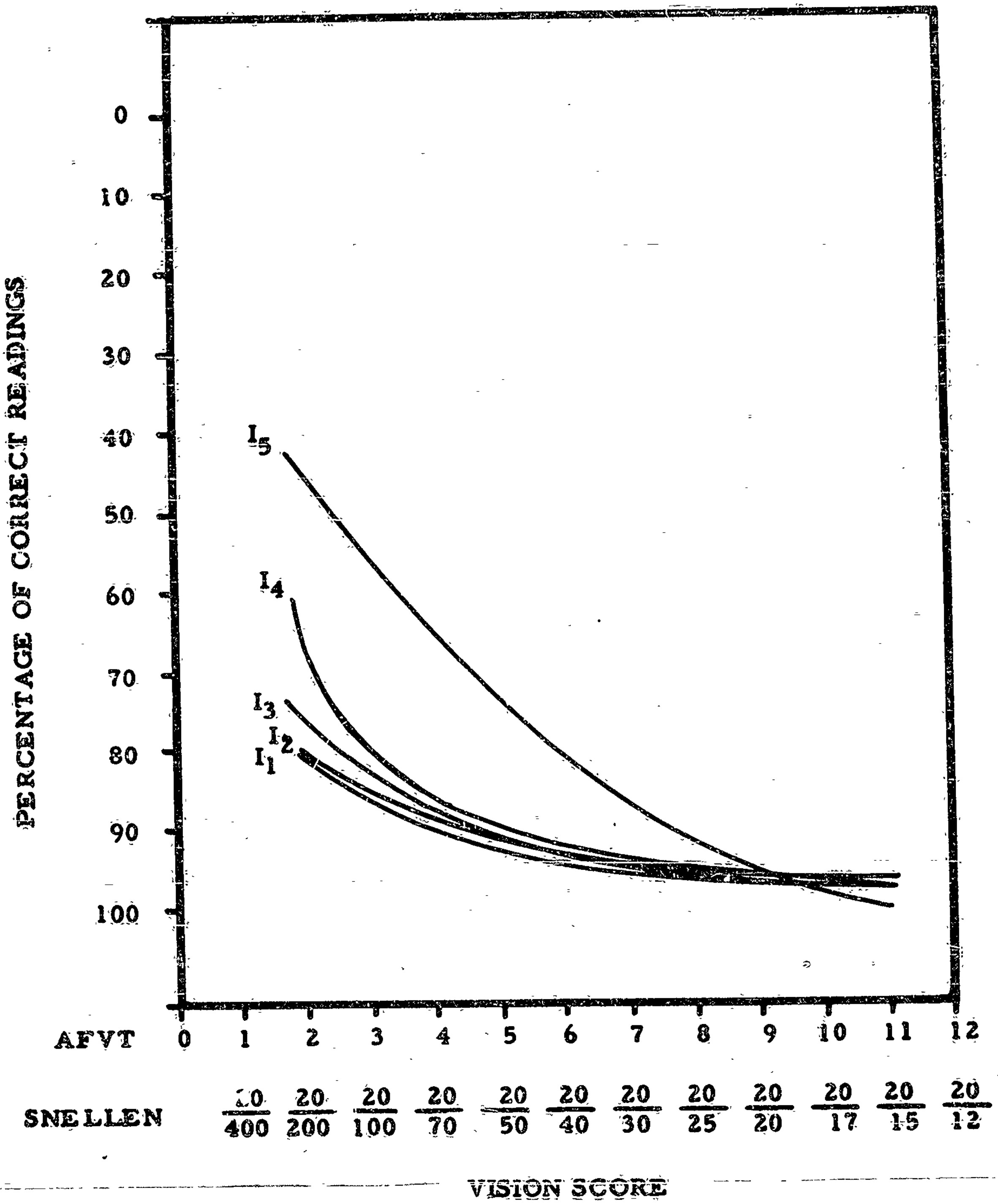

FIG. 17. COMPARISON OF RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL LEVELS OF ILLUMINATION AT DISTANCE 2.

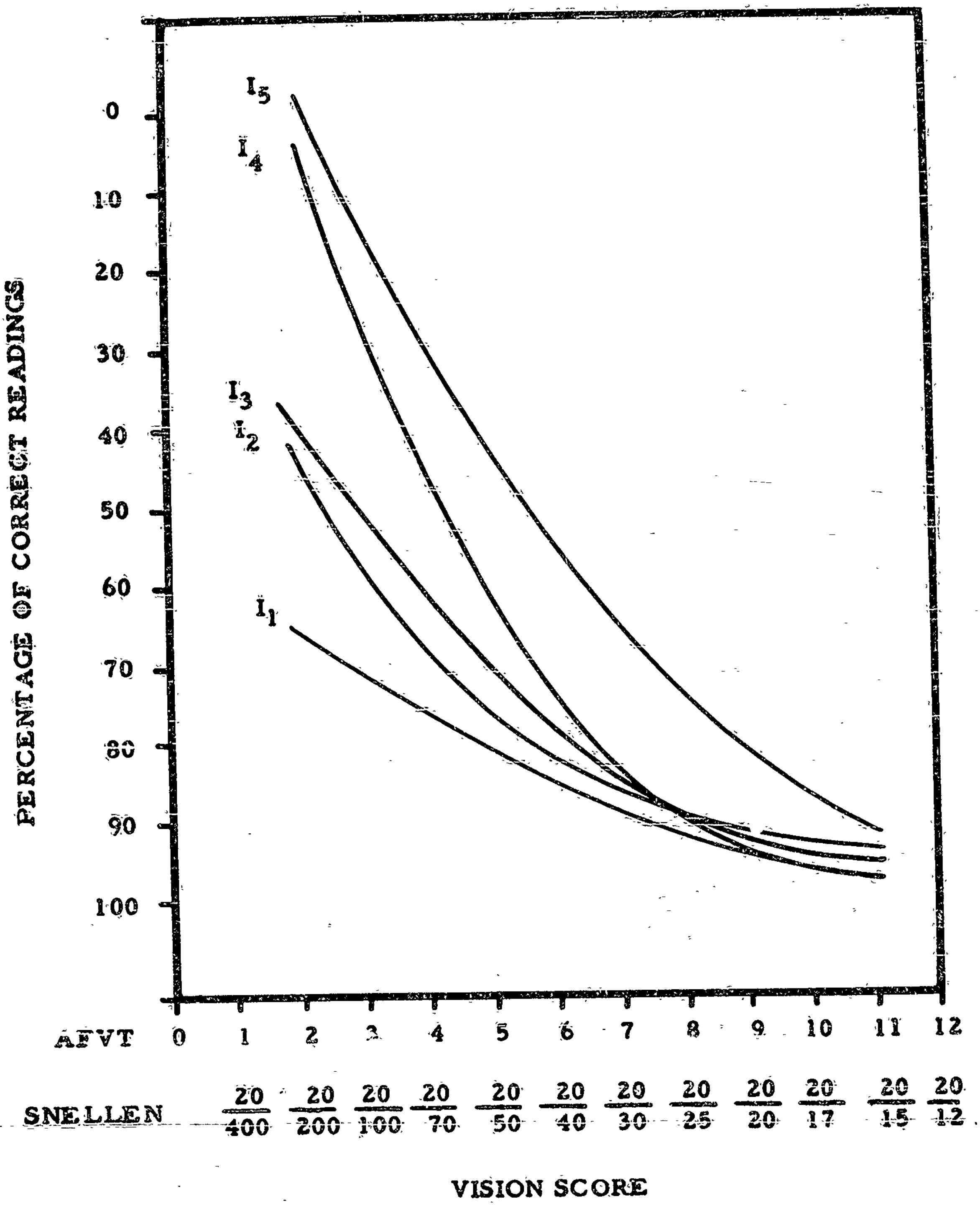

FIG. 18. COMPARISON OF RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER FOR ALL LEVELS OF ILLUMINATION AT DISTANCE 3.

effect of not meeting the assumption is to require larger F-ratios than the tabled values for significance, it would seem safe to conclude that these F-ratios are all significant at the 1% level of confidence.

The interactions of illumination and vision, and distance and vision, were of particular interest since they were concerned directly with the purposes of this project. As pointed out previously, if these interactions were significant then the performance curves would not be the same shape and if the interactions were not significant then the performance curves would be the same shape. These results show that if 5 performance curves were plotted, one for each of the 5 levels of illumination, they would not be the same shape and that visual standards established from these curves would be a function of illumination.

The same reasoning holds for the illumination and distance interactions. The fact that this is significant indicates that the visual standards inferred from the curve would be a function of the distance.

The results of the analysis of variance of the accuracy criterion show essentially the same results as the analysis of the time criterion. This is to be expected in view of the high correlation between the two measures ($r = .85$). The F-ratios of particular interest are those involving illumination and distance and illumination and vision interaction. These interactions were also significant. The meaning of this is that both distance and illumination affect visual standards taken from the performance curves.

<u>Performance Curves:</u> The results of the performance curves show that if visual standards for performance on a similar task under

similar conditions were to be established, the best prediction could be made by using the curve at the appropriate distance and level of illumination. Because the difference in the trend of performance is not the same at different levels of illumination and at different distances, results obtained under a given level of illumination and/or at a given distance cannot be generalized to other conditions of illumination and/or distance.

Conclusions

As stated previously the two major purposes of this study were:

(1) To determine the effect of illumination on the relationship between artificially altered vision and performance on a job-sample-test.

(2) To determine the effect of distance from the work on the relationship between artificially altered vision and performance on a job-sample-test.

From the results of this research it can be concluded:

(1) Changes in illumination do not change the performance of different levels of vision the same amount.

(2) Changes in distance from the task do not change the performance of different levels of vision the same amount.

In terms of the methodology of establishing visual standards as developed in Phase III, the results of this study indicate that both distance and illumination must be taken into consideration when establishing visual standards from performance curves; that curves developed from job performance under a given set of conditions of illumination and distance cannot be used to set standards for jobs performed under

dissimilar conditions.

Conclusions and Recommendations

The program of research conducted under contract N7onr-39423 consisted of one exploratory and three major experiments. Each of the experiments was designed to provide information pertinent to the basic objective of the contract. A methodology for establishing visual requirements for naval personnel was developed and evaluated. The extent to which results obtained by the methodology can be generalized was investigated. The relationship between certain visual functions and performance on a job-sample test was determined both statistically and graphically.

On the basis of the evidence obtained in the program of research conducted, the following conclusions appear warranted:

1. The methodology evaluated in Phase III of the program of research provides a feasible means of establishing visual standards. Free-hand curves fitted to plots of vision scores versus job-performance can be used to describe the relationship between vision and job-performance. Further, the problem of obtaining a range of vision for certain visual functions was solved by the use of clip-on crossed-cylinder lenses. Of further importance is the fact that technicians, directed by a professional psychologist, would be able to apply the methodology in the collection of experimental data.

2. On the basis of the evidence obtained in Phase III, only very limited generalization of results from one visual task to other visual tasks can be made, because the trend of performance on different visual tasks was not the same at different levels of vision.

3. On the basis of the evidence obtained in Phase IV, results obtained under a given set of conditions, (i.e. at a given level of illumination and at a given working distance from the visual task), cannot be generalized to other conditions because the trend of performance was not the same at different levels of vision for different conditions of illumination and distance from the visual task. Further, these results point out the desirability of maintaining standardized conditions on a battlestation.

4. Although not within the realm of this study, the results of the program of research conducted appear to have implications for equipment design. The results of Phase III clearly indicate that certain types of dials are read faster and more accurately at all levels of visual acuity than other types of dials. These results warrant the conclusion that operators with poorer visual acuity could perform at a given level of proficiency on certain dials as well as, or better then, operators with better acuity could perform on other types of dials. Further, the efficiency of operators at all levels of acuity would be increased by the use of certain types of dials.

5. For other conclusions see "Supplement to Technical Bulletin #53--", which for security reasons are classified.

Because the methodology for establishing visual standards developed and evaluated in Phase III and Phase IV of the research shows real possibility for application, the following procedure is recommended as a guide for its use:

1. The critical visual tasks for each battlestation assignment be identified.

   (a) Further work needs to be done on establishing a procedure for this function. However, procedures developed at the U. S. Naval Medical Research Laboratory, U. S. Naval Submarine Base, New London, Conn., by Dimmick and Farnsworth (6) are recommended for at least preliminary work.

2. Acceptable standards of performance for the identified visual tasks be agreed upon.

3. The level of illumination under which the task is performed be agreed upon.

4. The working distance from the dial be agreed upon.

5. The relationship between different visual functions and job performance be established by the following steps:

   (a) Select approximately ten naval personnel experienced on the visual task being studied.

   (b) Have each man perform the visual task at least ten times, at each of five levels of vision.

      (1) The five levels of vision should be obtained using five sets of clip-on crossed-cylinder oblique lenses, varying from plano to four diopters between the power of the crossed-cylinders.

6. Plot performance against near acuity score on the Armed Forces Vision Tester.

7. Draw a free-hand curve showing the relationship between vision and job performance.

8. Locate the minimum standard of performance agreed upon in Step B on the obtained curve, the visual score below that point being the visual standard for that task.

In the above procedure steps 2, 3, and 4 must be resolved at the policy making level. However, the remaining steps in the procedure can be performed by technicians, who are trained for the task. It appears reasonable to assume the amount of training required for the technicians would not be prohibitive; that a short intensive period of training would suffice.

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APPENDIX A

DISTRIBUTION OF VISUAL SKILLS OF SUBJECTS IN PHASE II

NEAR ACUITY BEST EYE

ORTHO	SNEL	N
15	20/13	16
14	20/14	8
13	20/15	21
12	20/17	25
11	20/18	20
10	20/20	3
9	20/22	1
8	20/25	
7	20/29	
6	20/33	
5	20/40	
°	°	
°	°	
°	°	
1	20/200	

NEAR ACUITY BOTH EYES

ORTHO	SNEL	N
15	20/13	4
14	20/14	3
13	20/15	12
12	20/17	27
11	20/18	24
10	20/20	13
9	20/22	9
8	20/25	2
7	20/29	
6	20/33	
5	20/40	
°	°	
°	°	
°	°	
1	20/200	

FAR ACUITY BEST EYE

ORTHO	SNEL	N
15	20/13	18
14	20/14	5
13	20/15	15
12	20/17	26
11	20/18	15
10	20/20	4
9	20/22	5
8	20/25	2
7	20/29	3
6	20/33	1
5	20/40	
°	°	
°	°	
°	°	
1	20/200	

FAR ACUITY BOTH EYES

ORTHO	SNEL	N
15	20/13	9
14	20/14	2
13	20/15	15
12	20/17	31
11	20/18	16
10	20/20	8
9	20/22	3
8	20/25	4
7	20/29	4
6	20/33	2
5	20/40	
°	°	
°	°	
°	°	
1	20/200	

Appendix A - Con't.

NEAR PHORIA LATERAL

ORTHO	DIOP	N
15	15.0EX	0
14	13.5EX	1
13	12.0EX	3
12	10.5EX	0
11	9.0EX	0
10	7.5EX	4
9	6.0EX	10
8	4.5EX	12
7	3.0EX	11
6	1.5EX	21
5	0.0	17
4	1.5ES	7
3	3.0ES	6
2	4.5ES	2
1	6.0ES	0

FAR PHORIA LATERAL

ORTHO	DIOP	N
15	6.66EX	0
14	5.66EX	1
13	4.66EX	1
12	3.66EX	0
11	2.66EX	2
10	1.66EX	11
9	.66EX	16
8	.33ES	28
7	1.33ES	14
6	2.33ES	6
5	3.33ES	8
4	4.33ES	2
3	5.33ES	1
2	6.33ES	1
1	7.33ES	3

NEAR PHORIA VERTICAL

ORTHO	DIOP	N
9	2.00RH	0
8	1.50RH	1
7	1.00RH	1
6	.50RH	4
5	.17RH	28
4	.17LH	50
3	.50LH	10
2	1.00LH	0
1	1.50LH	0

FAR PHORIA VERTICAL

ORTHO	DIOP	N
9	1.50RH	0
8	1.00RH	2
7	.50RH	5
6	.17RH	19
5	.17LH	54
4	.50LH	12
3	1.00LH	1
2	1.50LH	1
1	2.00LH	0

Appendix A - con't.

FAR DEPTH

ORTHO	N
9	26
8	12
7	7
6	7
5	10
4	9
3	14
2	1
1	2
0	6

FAR COLOR

ORTHO	N
6	84
5	4
4	4
3	1
2	1
1	
0	

APPENDIX B

PRESCRIPTIONS OF SPECTACLES FITTED TO EACH SUBJECT IN PHASE III & IV

APPENDIX B

PRESCRIPTIONS PREPARED FOR SUBJECTS IN EXPERIMENT

Subject No.	O.D.	O.S.
1	+ .25 sphere	Plano
2	- .25 - .75 x 95	- .25 - 1.25 x 90
3	+ .25 - .62 x 2	- .37 x 180
4	+ .50 - 1.25 x 15	+ .25 - 1.00 x 165
5	+ .50 - .25 x 110	+ .25 - .37 x 52
6	+ .50 - .75 x 3 = 2^{Δ} B.I.	+ .25 - .25 x 162 = 2^{Δ} B.I.
7	+ .25 - .25 x 65	- .25 x 103
8	+ .25 sphere	+ .50 - .25 x 135
9	-1.00 - .25 x 100	- .75 - .75 x 90
10	-1.25 - .50 x 91	-1.00 - .75 x 80

O.D. is the prescription for right eye.
O.S. is the prescription for left eye.

APPENDIX C

PRESCRIPTIONS FOR CLIP-ON CROSSED-CYLINDER LENSES

APPENDIX C

Prescriptions of crossed cylinder lenses and astigmatic error produced.

Lens No.	O.D.	O.S.	Astigmatism
1	Plano	Plano	None
2	- .50 ≠ 1.00 x 135	- .50 ≠ 1.00 x 45	1.00 Diopter
3	-1.00 ≠ 2.00 x 135	-1.00 ≠ 2.00 x 45	2.00 Diopters
4	-1.50 ≠ 3.00 x 135	-1.50 ≠ 3.00 x 45	3.00 Diopters
5	-2.00 ≠ 4.00 x 135	-2.00 ≠ 4.00 x 45	4.00 Diopters

APPENDIX D

BARTLETT TESTS AND TRANSFORMATIONS OF THE DATA, PHASE III & IV

APPENDIX D

Transformations of the Data

__Phase III.__ The analysis of variance is a technique for testing the hypothesis that several samples have been drawn at random from a common normal population (7). However, if the variances within the various samples are dissimilar, conclusions concerning the experimental means may not be possible. Therefore, a test of the hypothesis that the samples are random samples from populations with a common variance is necessary before applying analysis of variance.

Bartlett (1) has developed a method for testing homogeniety of variance that is evaluated as Chi-square. This test, as described by Edwards (6, p. 196), was applied to the time data. A Chi-square value of 7146.59 was obtained. As Chi-square is not tabled to 499 degrees of freedom, (one less than the number of groups), the Chi-square significant at the 1% and 5% level of confidence was determined using the method outlined by Peters and Van Voorhis (20, p. 419). For 499 degrees of freedom a Chi-square value of 574.95 is significant at the 1% level of confidence and a Chi-square value of 551.78 is significant at the 5% level. Therefore, as the obtained Chi-square was significant beyond the 1% level, the hypothesis these variances were a random sample from populations with a common variance was rejected.

Because the assumption of homogeniety of variance was not tenable, it was necessary to transform the data. On the basis of estimations of the proper transformation obtained by the method outlined by Bartlett (2), and by Kempthorne (14, p. 156), a logarithmic transformation of the data was performed. The Bartlett test was then applied to the

Appendix D - Con't.

transformed data. A Chi-square value of 3811.59 was obtained. As the obtained Chi-square was significant beyond the 1% level of confidence the hypothesis the variances of the transformed data were a random sample from populations with a common variance was rejected.

Because the time data, transformed by the logarithmic transformation, did not meet the assumption of homogeniety of variance, a log transformation of the log time scores was performed. Bartlett's test was then applied to the data transformed by the log log function. A Chi-square of 1740.81 was obtained. As the Chi-square was significant beyond the 1% level the hypothesis the variances were from populations with a common variance was rejected.

However, there were 19 cells in the factorial design which had a variance of zero. In the Bartlett test of the raw time scores the logs of zero cell variances were arbitrarily treated as 10^{-2}. In the Bartlett test of the log time scores they were treated as 10^{-5} and in the log log time score at 10^{-5}. Because the values assigned to the log of these cells were arbitrarily determined, it was decided to determine the effect of other values on the results of the Bartlett test.

Treating the log of the cells with zero variance as zero, a Chi-square of 1913.11 was obtained for the log time scores. Although significant beyond the 1% level this Chi-square was much smaller than the Chi-square previously obtained. On the log log time scores the log of the cells with zero variance was treated as 10^{-2}, and a Chi-square of 601.80 was obtained. This value just attains significance at the 1% level as Chi-square with 499 degrees of freedom must attain a Chi-square of 574.95 to be significant at the 1% level.

The Bartlett test was then applied to the log log time scores treating the log of the 19 cells with zero variance as 10^{-1}. The obtained Chi-square was 222.10, which does not attain statistical significance. Therefore, using this procedure, the data offer no evidence against the hypothesis these variances were a random sample from populations with a common variance. When the cells with zero variance were treated as zero, the results were the same, as a Chi-square value of -157.59 was obtained. This value was regarded as a random fluctuation from zero, as a Chi-square value must necessarily be positive.

On the basis of the evidence obtained from the Bartlett test, it was assumed no marked heterogeniety existed in the data when transformed by the log log function. Lindquist (16) states, that unless there is marked heterogeniety in the data, there is little effect on the F-distribution. Therefore, it was concluded the log log time scores could be treated by analysis of variance, taking into account the fact the level of significance obtained might be very slightly inflated.

Phase IV. The assumption of homogeniety of variance of the time data collected in the experiment conducted in Phase IV was also tested by the Bartlett test. When applied to the raw time scores a Chi-square value of 11,221.97 was obtained. A Chi-square of this magnitude with 749 degrees of freedom was significant beyond the 1% level of confidence, so the assumption was not satisfied.

An estimate of the proper transformation to achieve homogeniety of variance was obtained in the same manner as in Phase III. On the basis of the obtained estimate, logarithmic transformation of the data was performed. A Chi-square of 2298.04 was obtained from a Bartlett

test of the log time scores. As this value was significant beyond the 1% level, the assumption still was not satisfied. A log transformation of the log time scores was then made. A Chi-square of 1667.17 was obtained by the Bartlett test. This value was significant beyond the 1% level of confidence so the log log transformation did not meet the homogeniety assumption.

On the basis of a pictorial representation of the data it appeared as if the reciprocals of the time scores might meet the homogeniety assumption. However, the Chi-square obtained from the Bartlett test of the reciprocal transformation was 3660.74 which did not meet the assumption.

Because the minimum performance time on the job-sample was about two hundredths of a minute it seemed logical that the homogeniety assumption might be tenable when a constant was subtracted from the time score. Therefore, the approximate minimum performance time was subtracted from each time score and Bartlett tests performed on log, log log, and reciprocal transformations of these scores. In all cases the obtained Chi-square was larger than that obtained on the log log transformation of the raw time scores, so the assumption of homogeniety of variance was not satisfied.

As the variance of the log log transformation of the raw time scores was the least heterogenous, it was decided to proceed with the analysis of variance using the log log time scores. Because the variance of these data was not homogenous, when interpreting the results it was necessary to take into consideration the fact that the level of significance of each of the effects in the analysis would probably be overestimated. Realizing this limitation of the analysis it was necessary to interpret the results with extreme care.

APPENDIX E

AVERAGE BEST EYE NEAR ACUITY SCORES, PHASE III & IV

APPENDIX E

Average Best Eye Near Acuity Scores, Phase III & IV

Average Near Acuity Best eye Score on Armed Forces Vision Tester for all Subjects With Each Set of Clip-on Crossed Cylinder Lenses.

Subject	No. 1	No. 2	No. 3	No. 4	No. 5
1	10.6	7.6	4.1	3.0	2.0
2	10.9	8.2	4.0	3.4	2.3
3	10.7	9.0	5.7	4.2	3.7
4	11.3	9.0	6.4	4.3	3.6
5	11.1	9.0	5.5	4.0	3.3
6	11.0	7.8	5.0	3.7	2.3
7	11.0	8.7	6.7	4.0	3.7
8	11.1	10.2	7.3	5.8	4.6
9	10.8	9.1	6.3	5.8	4.4
10	11.1	9.5	6.4	5.3	4.1

APPENDIX F

CURVE FITTING & CURVES, PHASE III & IV

APPENDIX F

Curve Fitting

Phase III. The functional relationship between two variables may be expressed either graphically by a curve, or algebraically by an equation where a change in one variable is accompanied by specific changes in the other. In this research both methods of expressing the relationship between near visual acuity and performance on the job-sample test were used.

Using Ezekiel's method of averaging (8), graphical curves representing the relationship between near visual acuity and performance on both the time and accuracy criteria were developed. In addition the functional relationship between the two variables of near acuity and performance was determined algebraically for all dials on the time criterion.

The first step in the time analysis was the computation of the ~~average vision score~~, best eye near acuity on the AFVT, for all measurements on each subject while wearing each set of the different clip-on lenses, and the mean performance time of the ten trials in each cell. A set of graphs for each dial was then plotted with performance time on the ordinate and near visual acuity scores on the abscissa. Each set consisted of a graph for each subject on that dial. Each individual graph contained five points, (mean performance time plotted against mean vision score), which were connected by straight lines on dials with flat curves and free-hand curves on dials with marked differences in performance. No line extended beyond the actual range of vision scores for that subject.

A composite graph was then constructed for each dial based on the

ten individual performance graphs in the set. Time performance values for each acuity score in the range of vision on the individual graph were plotted on the composite graph. This resulted in a fewer number of points on scores near the extremes of the range of vision as the range of vision differed for the different subjects. Free-hand curves, fitted by eye, were drawn to the 77 points on the composite graphs. The fact that there were fewer points at the extremes of the range of acuity scores was taken into account in drawing the curves. In every instance the free-hand curves drawn to the composite plots were curvilinear. From inspection of the curves it appeared logical that some mathematical function, describing a curvilinear relationship would fit the observed data for all dials. Because of the apparent curvilinearity of the data for Dial 7, it was felt that the mathematical function that would adequately describe the relationship between visual acuity and performance on that dial would adequately describe the relationship between near acuity and performance on most of the other dials.

Three logarithmic curves, a parabola, a straight line, and an inverse function, were fitted to the composite data for Dial 7. The log functions were plotted on log, semi-log, and log log graph paper. The rest were fitted by the least squares method. Inspection of the three logarithmic plots showed a logarithmic function would not adequately fit the data. The straight line and the parabola also provided a poor fit to the data. The inverse function provided the best fit using least squares as a criterion. In addition comparison of the free-hand and inverse curves for Dial 7 revealed they were of essentially the same shape and magnitude. On the basis of the least squares fit and the comparison with the free-hand curve it was concluded the inverse

curve provided an adequate fit to the data. The general formula for the inverse function used was $y = ax' + b$ where x' was the reciprocal of x, and a and b were straight line constants. The constants, a and b, were solved by the formulas:

$$a = \frac{n\Sigma xy - \Sigma x \Sigma y}{n\Sigma x^2 - (\Sigma x)^2} = \text{straight line}$$

and

$$b = \frac{\Sigma x^2 \Sigma y - \Sigma x \Sigma xy}{n\Sigma x^2 - (\Sigma x)^2} = \text{straight line}$$

Because the inverse function appeared to adequately describe the data for Dial 7, curves were developed for all dials using the inverse function fitted to the 77 points on the composite graphs. Comparison with free-hand curves drawn to plots of the composite data revealed the two curves for each dial were practically identical in all cases.

It was felt that curves, fitted to the 50 points of the raw averages available for each dial would reduce the chance for error present in the plots of 77 points. Therefore, inverse curves were fitted to the points of the 50 raw averages for each dial. The differences in the curves fitted to the two sets of data can be evaluated by the difference in the size of the straight line constants, a and b, for the two sets of data. The constants are given in Table 14.

TABLE 14

Straight Line Constants for Curves Fitted to Two Sets of Data

Dial Number	Composite Data N=77		Composite Data N=50	
	a	b	a	b
1	1.46	2.60	1.45	2.64
2	3.84	2.22	3.82	2.29
3	1.37	2.54	2.28	2.42
4	11.23	1.74	10.95	1.97
5	7.42	2.23	6.07	2.46
6	25.77	0.72	33.45	-0.25
7	20.81	2.25	29.08	1.29
8	9.11	2.39	10.65	2.41
9	4.18	2.41	4.69	2.37
10	8.92	2.99	8.32	3.13

The actual formula used for the curves was, $t = \frac{a}{v} + b$, where t is performance time, v is vision score, and a and b are the straight line constants. The formulas for the curves fitted to the 50 raw averages for each dial, showing the value of the straight line constants are given in Table 15.

TABLE 15

Formulas For Time Curves Fitted To

50 Raw Averages For Each Dial

Dial 1	$t = \frac{1.45}{v} + 2.64$
Dial 2	$t = \frac{3.82}{v} + 2.29$
Dial 3	$t = \frac{2.28}{v} + 2.42$
Dial 4	$t = \frac{10.95}{v} + 1.97$
Dial 5	$t = \frac{6.07}{v} + 2.46$
Dial 6	$t = \frac{33.65}{v} - 0.24$
Dial 7	$t = \frac{29.08}{v} + 1.29$
Dial 8	$t = \frac{10.65}{v} + 2.41$
Dial 9	$t = \frac{4.69}{v} + 2.37$
Dial 10	$t = \frac{8.32}{v} + 3.13$

The manner in which the curves fit the data is illustrated in Figure 19. Further illustration is provided by the straight line fit shown in Figure 20.

Comparison of the mathematical and free-hand curves fitted to the plots of raw averages showed them to be practically identical for all dials. However, in the case of Dials 1, 2, 3, and 5, it appeared as if

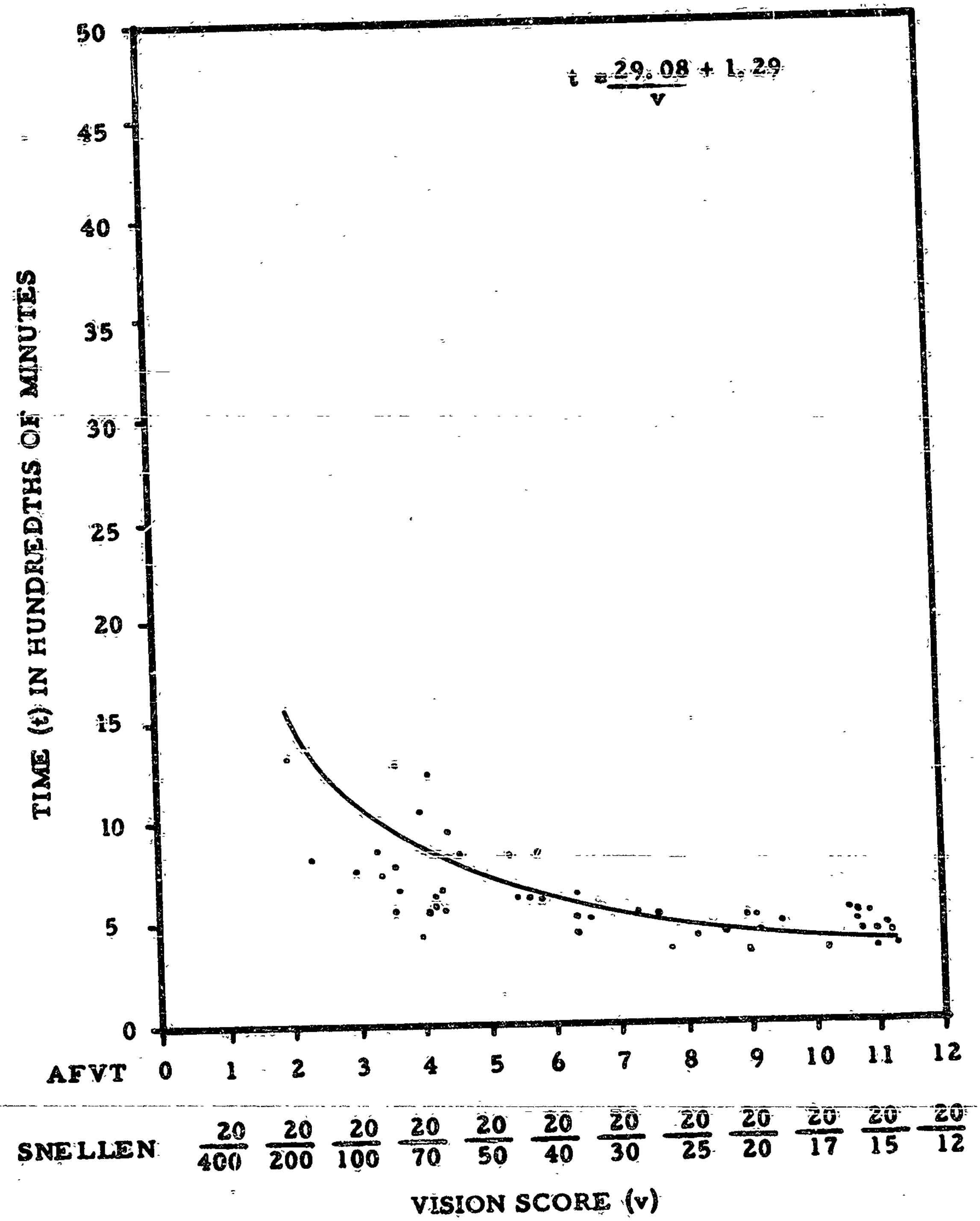

FIG. 19. ILLUSTRATION OF THE FIT OF THE INVERSE CURVE TO THE 50 AVERAGED POINTS ON DIAL 7.

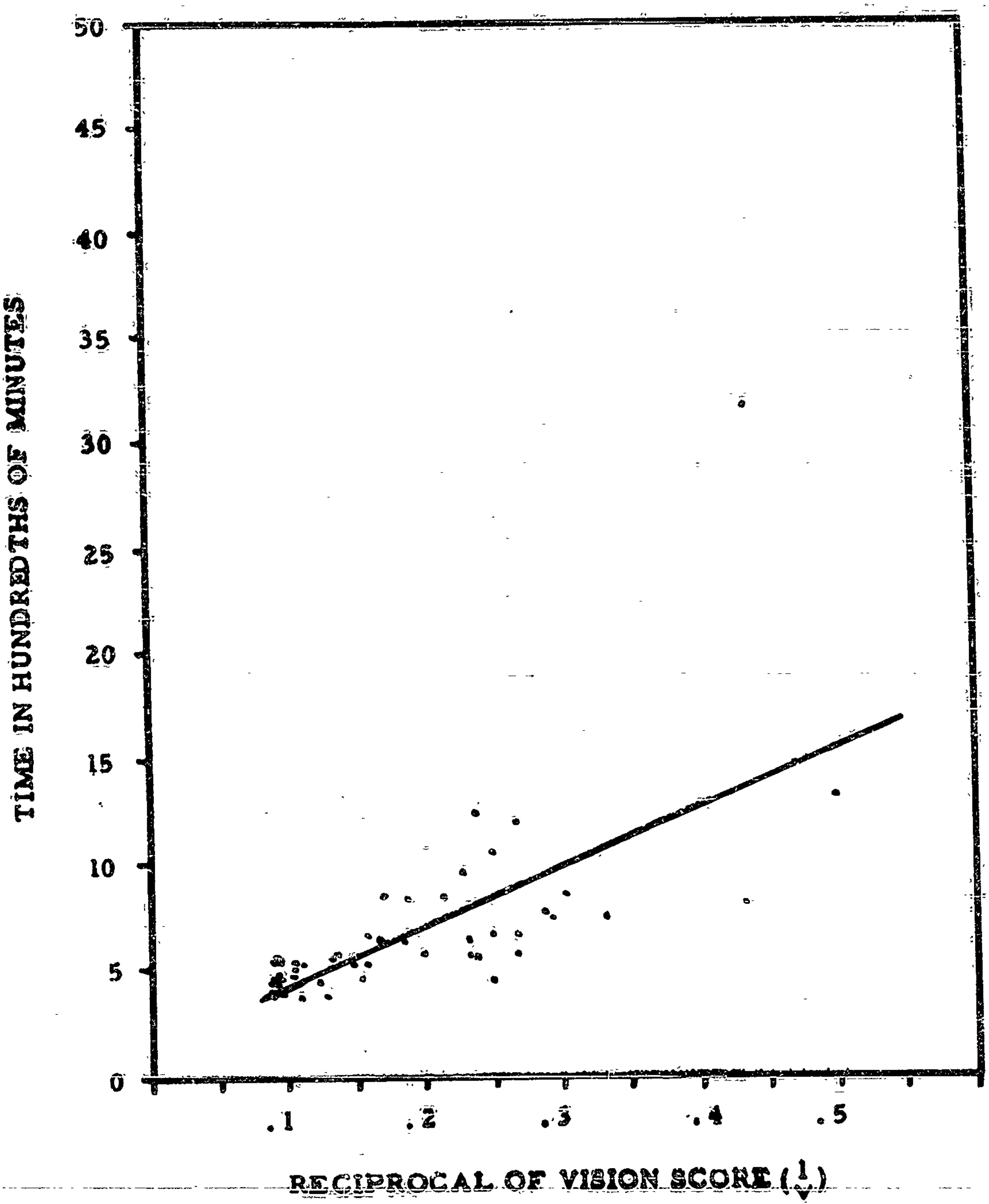

FIG. 20. ILLUSTRATION OF THE FIT OF A STRAIGHT LINE TO THE 50 AVERAGED POINTS FOR DIAL 7 WITH DATA TRANSFORMED BY THE INVERSE FUNCTION ($v' = \frac{1}{v}$).

a straight line might provide a better fit. Therefore, a least squares straight line was fitted to the data for these four dials. The sum of the least squares for the two functions are given in Table 16.

TABLE 16

Sum of Least Squares of Inverse and Straight Line For Four Dials

Dial No.	Sum of Least Squares, Best Inverse Line	Sum of Least Squares, Best Straight Line
1	9.99	9.03
2	17.16	14.03
3	7.14	7.96
5	42.04	53.55

Using least squares as a criterion the best inverse curve provided a better fit to the data on dials 3 and 5 than the best straight line. On dials 1 and 2 the straight line provided the better fit to the data. However, the difference between the sum of the least squares for the two functions is relatively small for dials 1 and 2. Therefore, it was concluded that it was justifiable to use the inverse curve to represent the relationship between vision and performance for all the dials in the job-sample test.

The inverse curve fitted to the data is asymtotic to two lines, the Y and X intercepts. Inspection of the curves raised doubt whether the curves were asymtotic to the time (Y) axis in all cases. The inverse curve for dial 6 appeared to depart the farthest from the Y asymtote, so it was decided to shift the time axis to a point other than a vision score of zero and determine the effect on the curve. Therefore, the time axis was shifted from the point of zero score on near acuity to near acuity scores of 1 and 1.5, and least squares inverse curves developed. The sum of the least squares for the three

curves is shown in Table 17.

TABLE 17

Sum of Least Squares For Inverse Curves Fitted to The Data For Dial Six With Time Axis Located At Three Different Points

Sum of Least Squares Best Inverse Curve	Condition of Axis
279.39	No shift
232.33	Shift 1 unit
235.29	Shift 1.5 units

The formulas for the three curves for dial 6 are presented in Table 18.

TABLE 18

Formulas for Three Curves for Dial 6

Condition of Axis	Formula
No shift	$t = \frac{33.65}{v} - 0.24$
Shift 1 unit	$t = \frac{18.38}{v-1} + 1.42$
Shift 1.5 unit	$t = \frac{10.03}{v-1.5} + 2.82$

The three curves based on these formulas are shown in Figure 21.

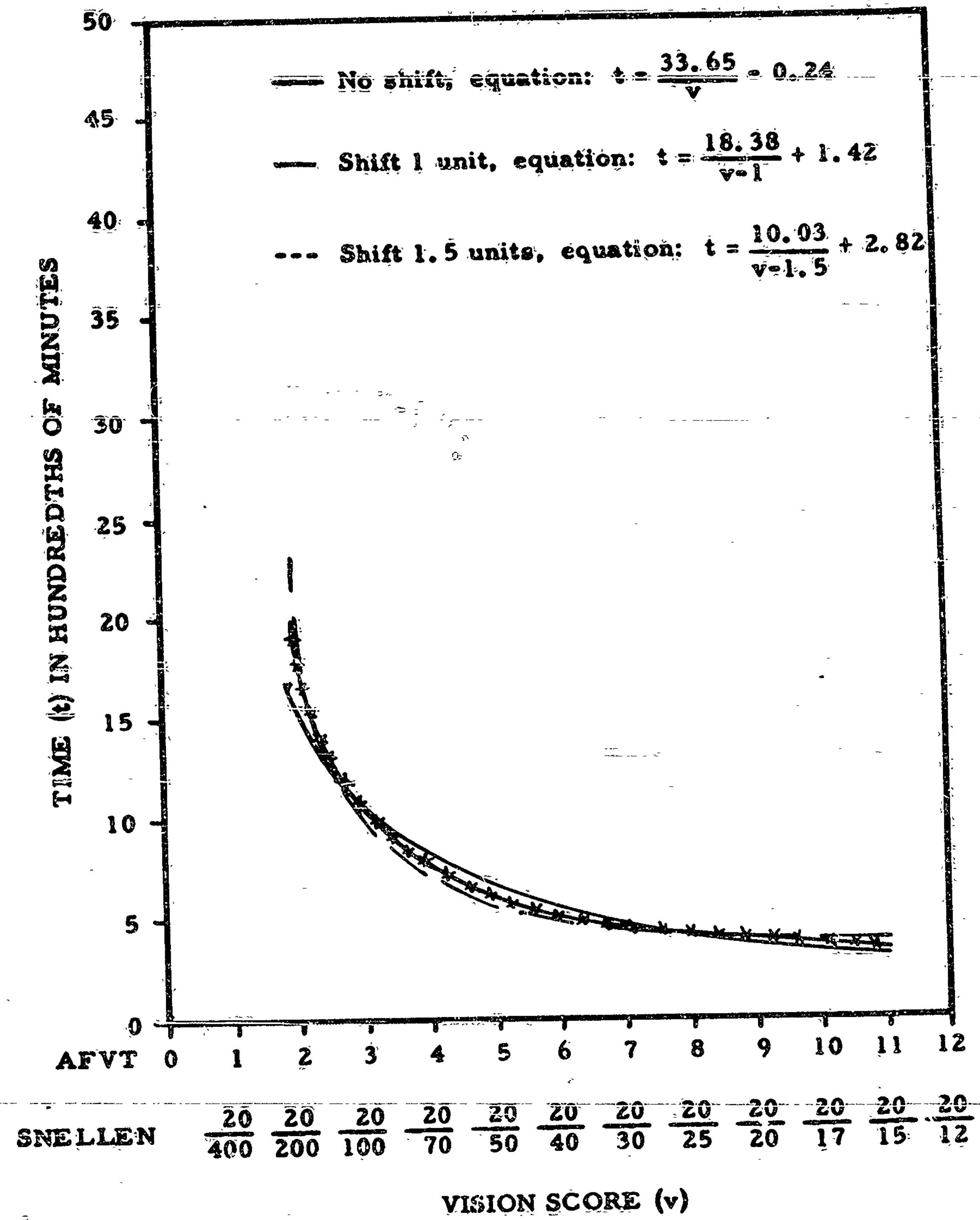

FIG. 21. COMPARISON OF RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 6 WITH TIME AXIS LOCATED AT VISION SCORES OF 0, 1 AND 1.5.

On the basis of the least squares criterion the best fit is provided to the data for this dial when the time axis is shifted to the near acuity score of one. However, inspection of the curves showed that shifting the Y-asymtote did not essentially affect the magnitude or the shape of the curve. Therefore, although the problem of the true zero point on the vision score axis is of great theoretical interest, in this instance it has little or no practical significance. As the curve for dial 6 departed the farthest from the Y-asymtote, and as the shift in the time axis resulted in very little change in the shape of the curve, the inverse curves fitted to the data for the other dials should be asymtotic, or nearly so, to the time axis located at the near acuity score of zero.

The time performance curves developed for the different dials using the inverse function are presented in Figures 22 through 31.

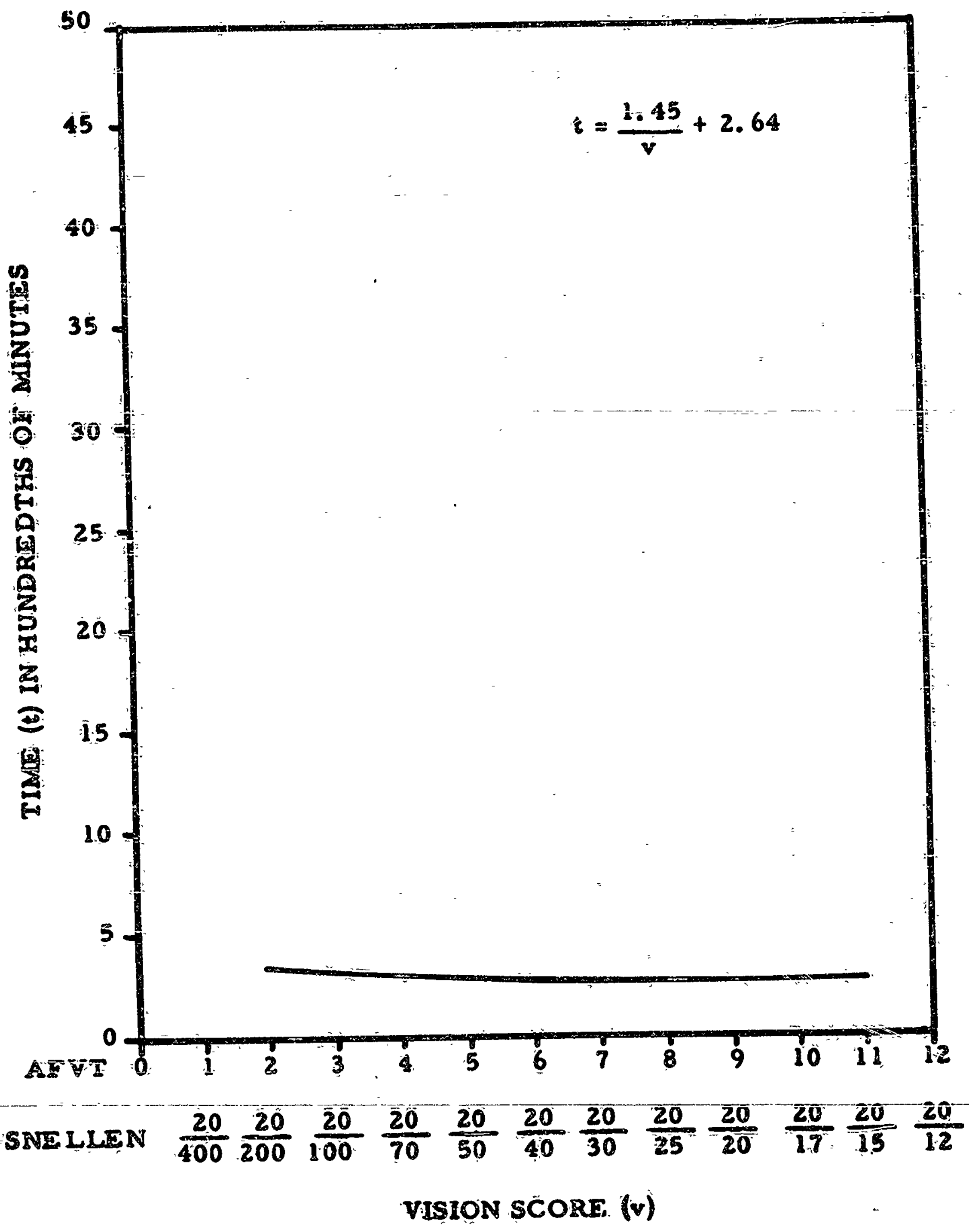

FIG. 22. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 1.

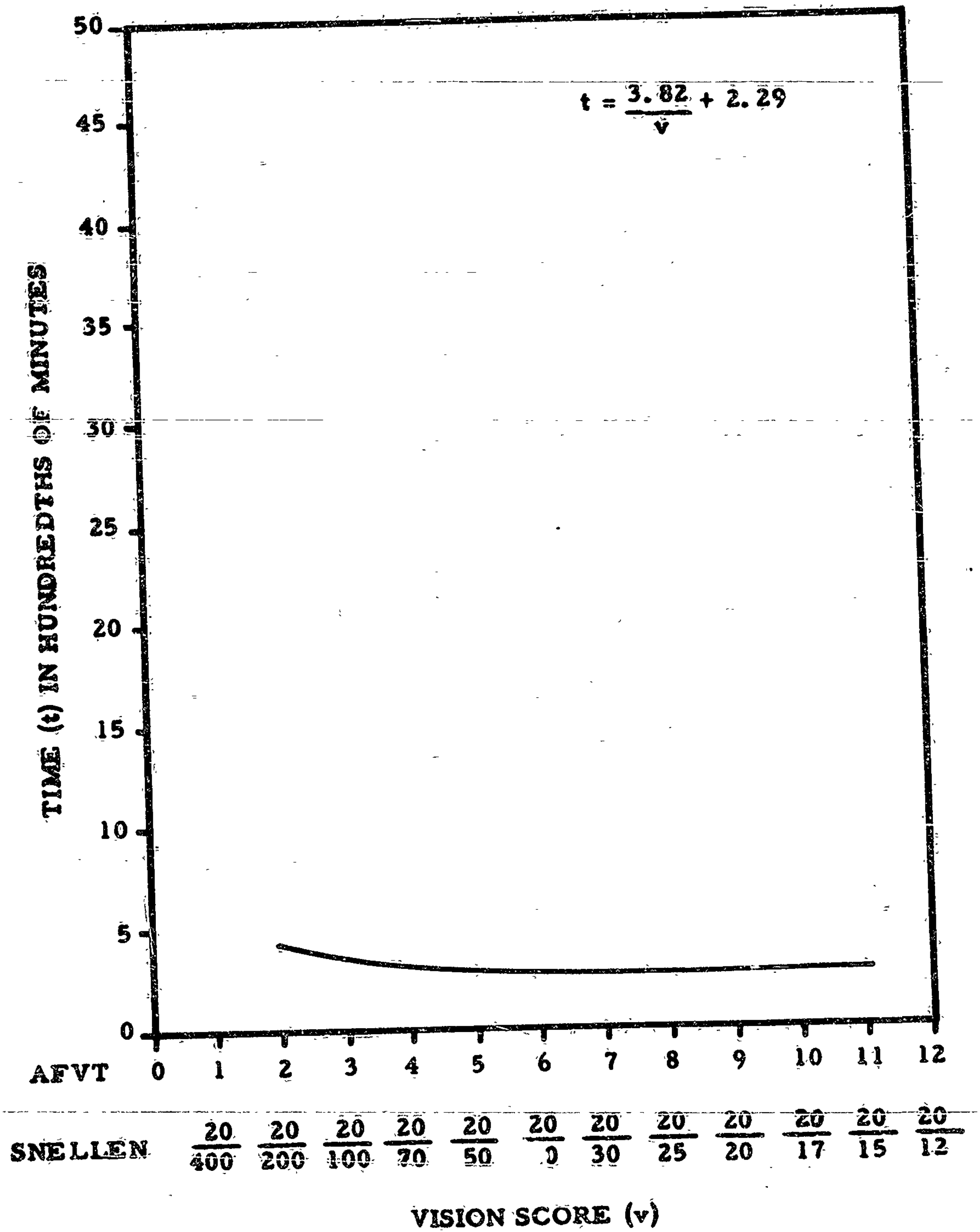

FIG. 23. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 2.

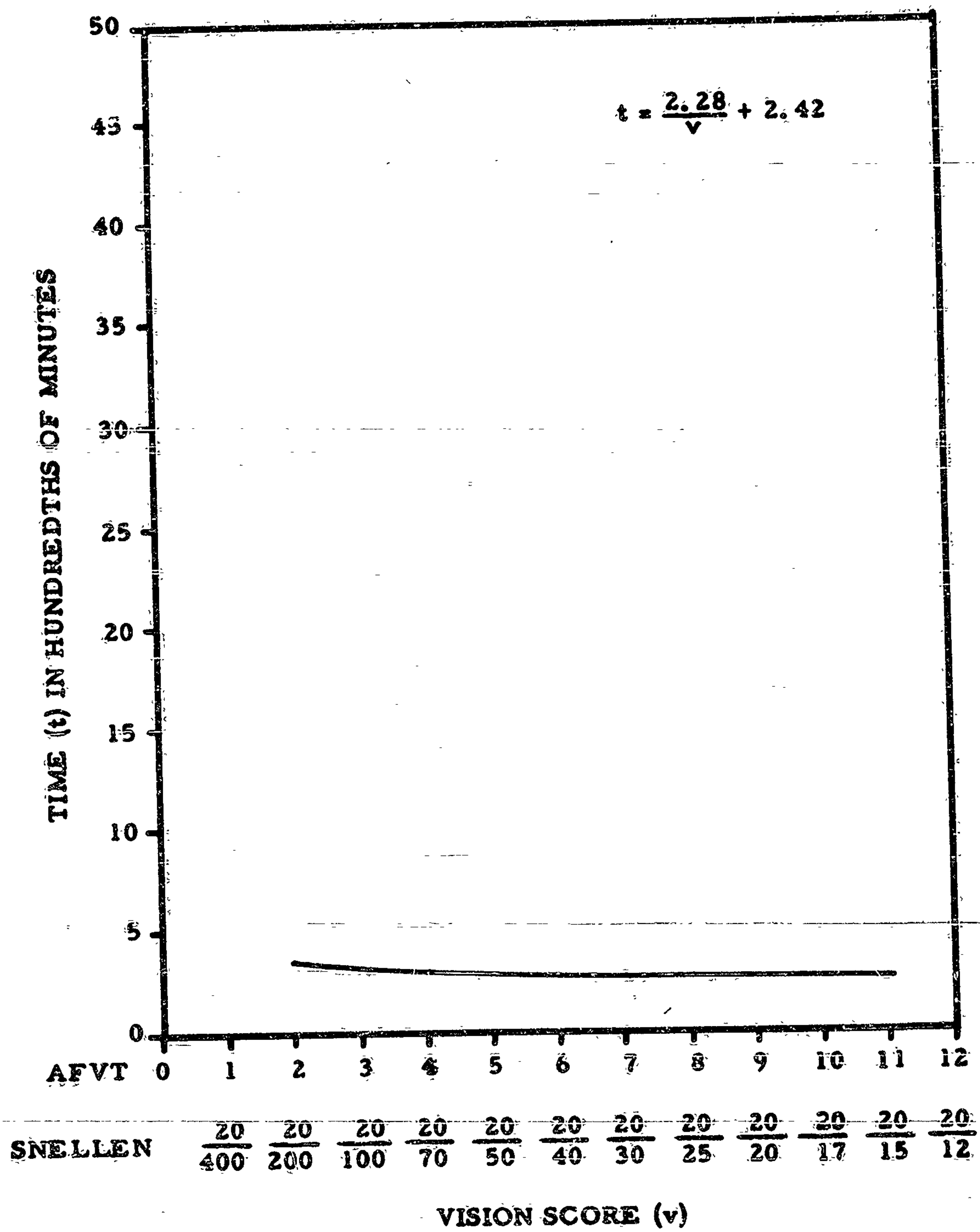

FIG. 24. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 3.

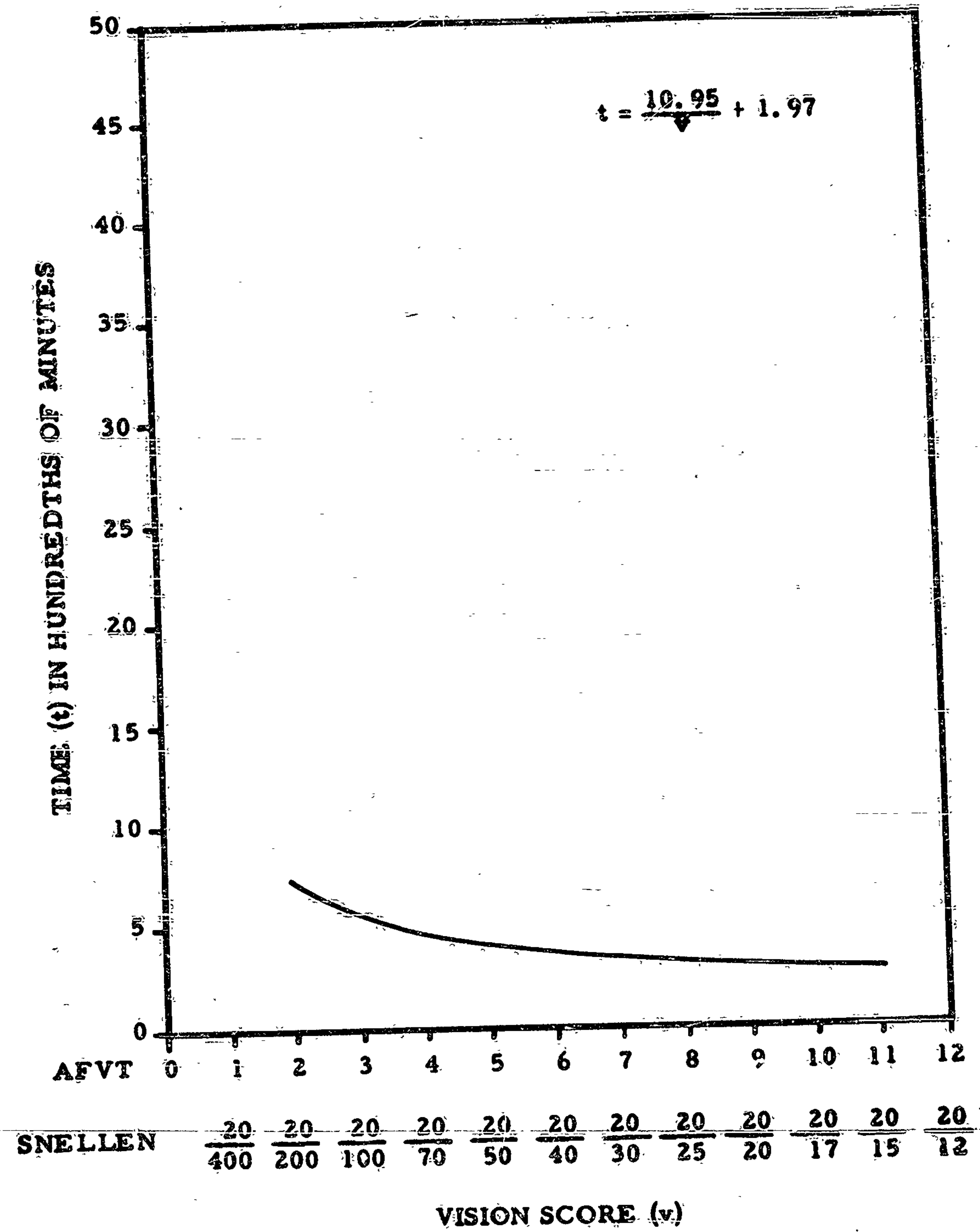

FIG. 25. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 4.

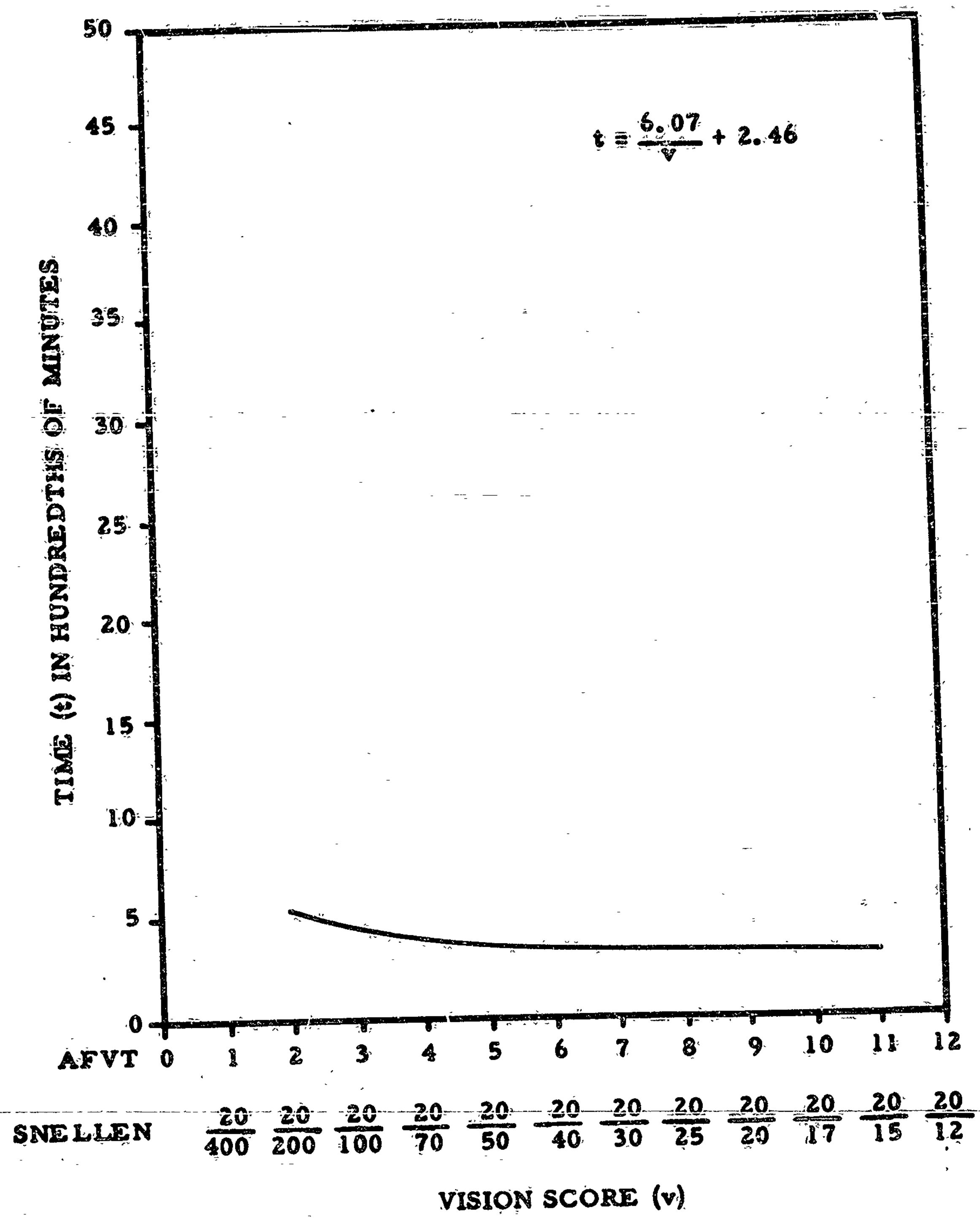

FIG. 26. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 5.

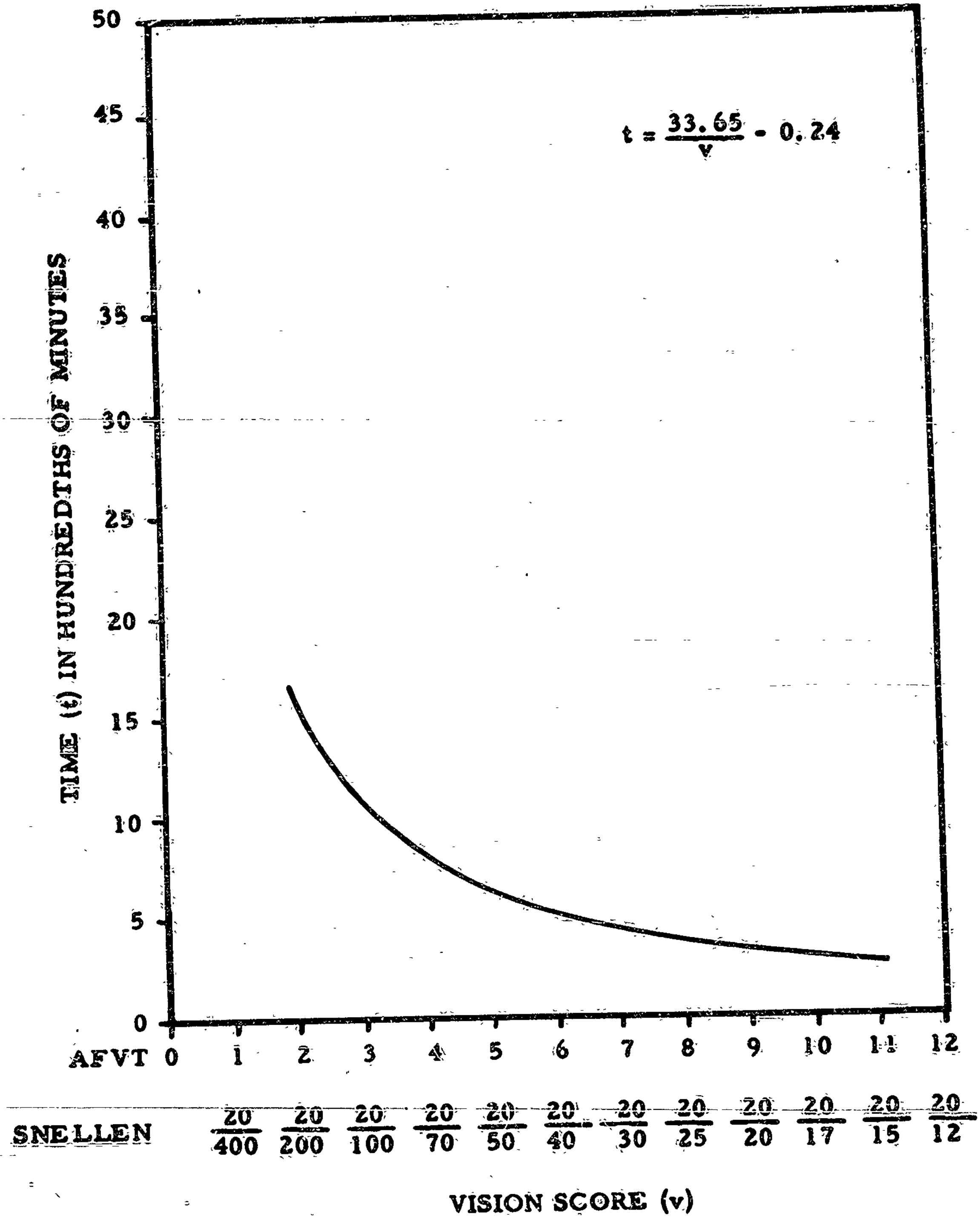

FIG. 27. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 6.

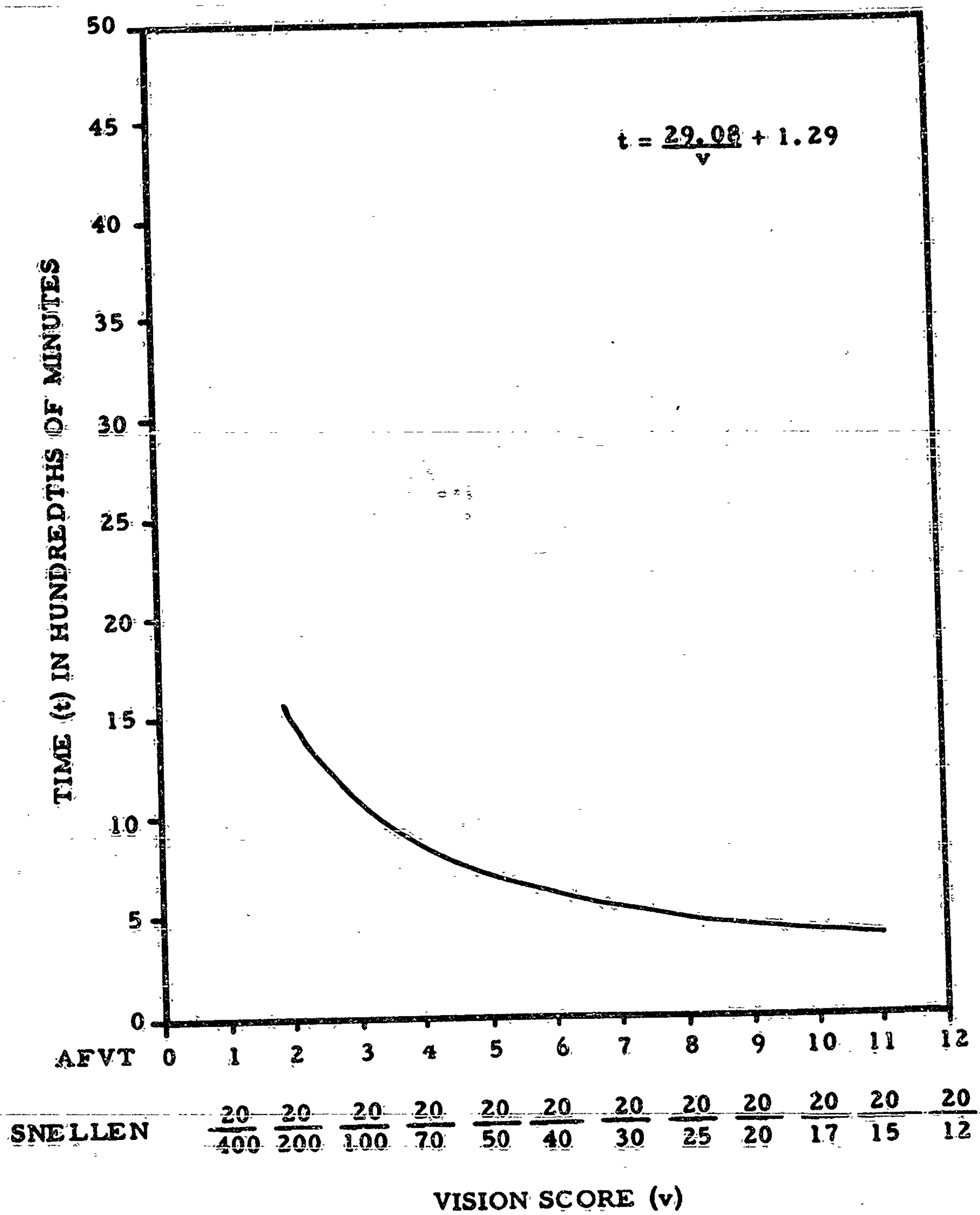

FIG. 28. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 7.

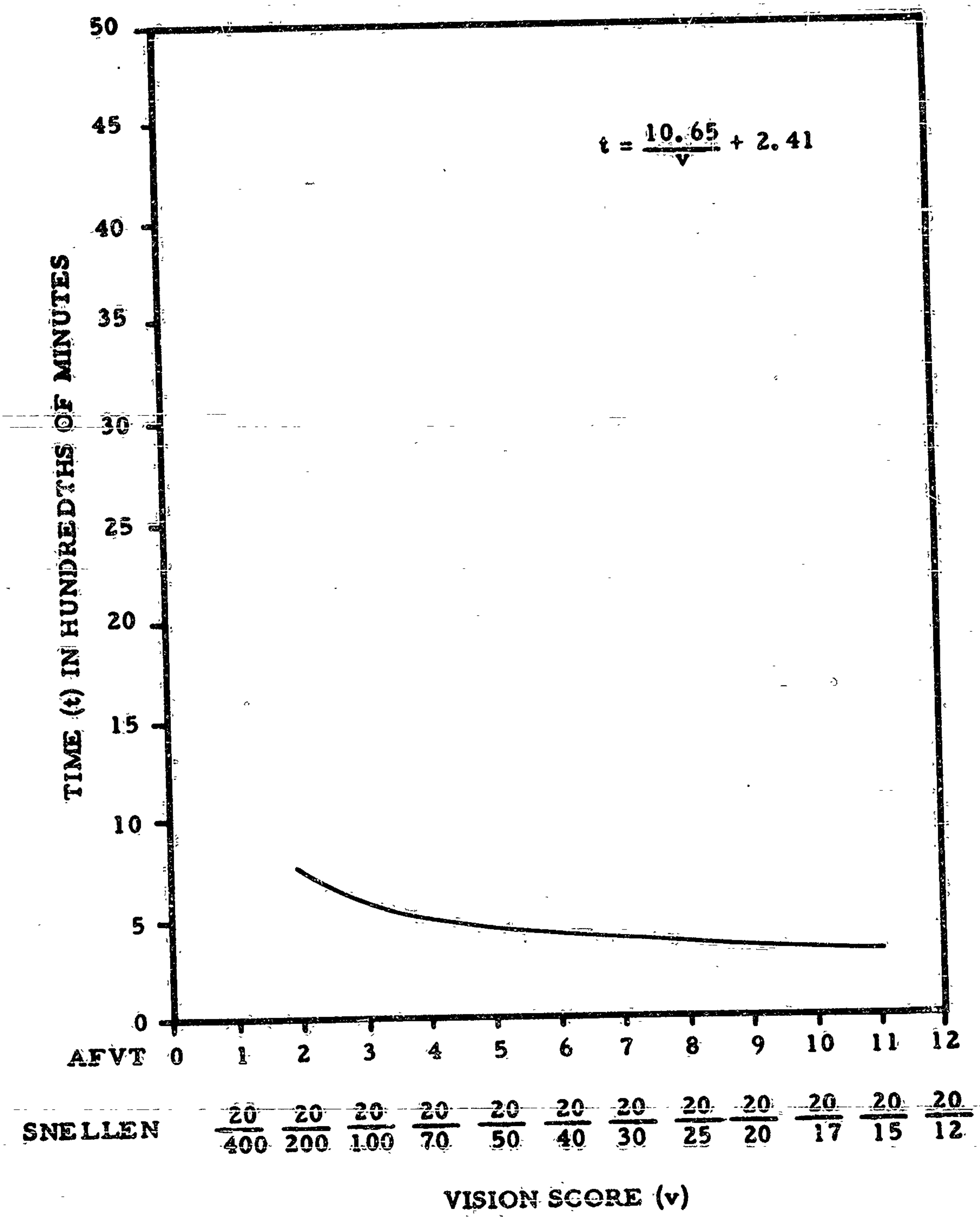

FIG. 29. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 8.

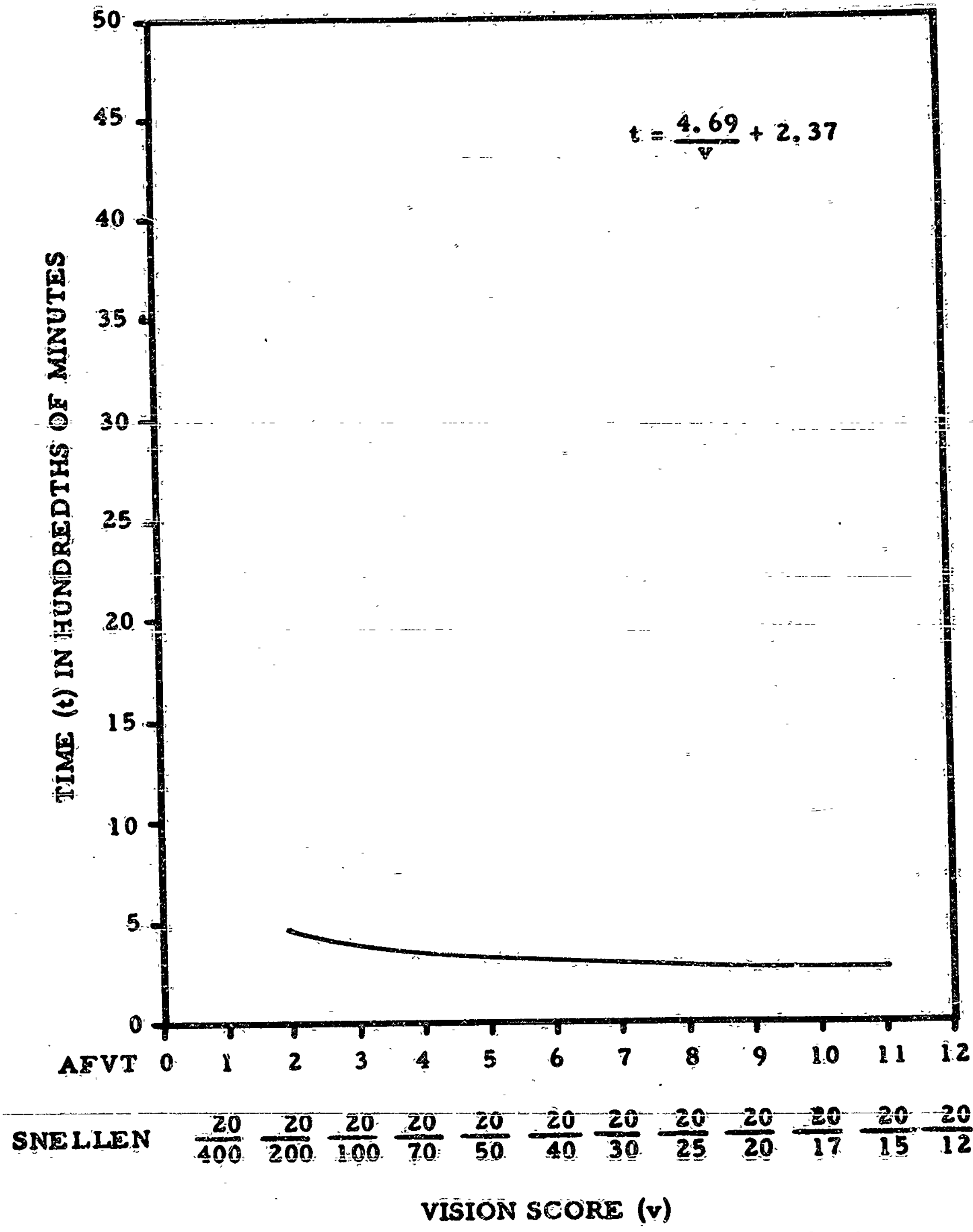

FIG. 30. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 9.

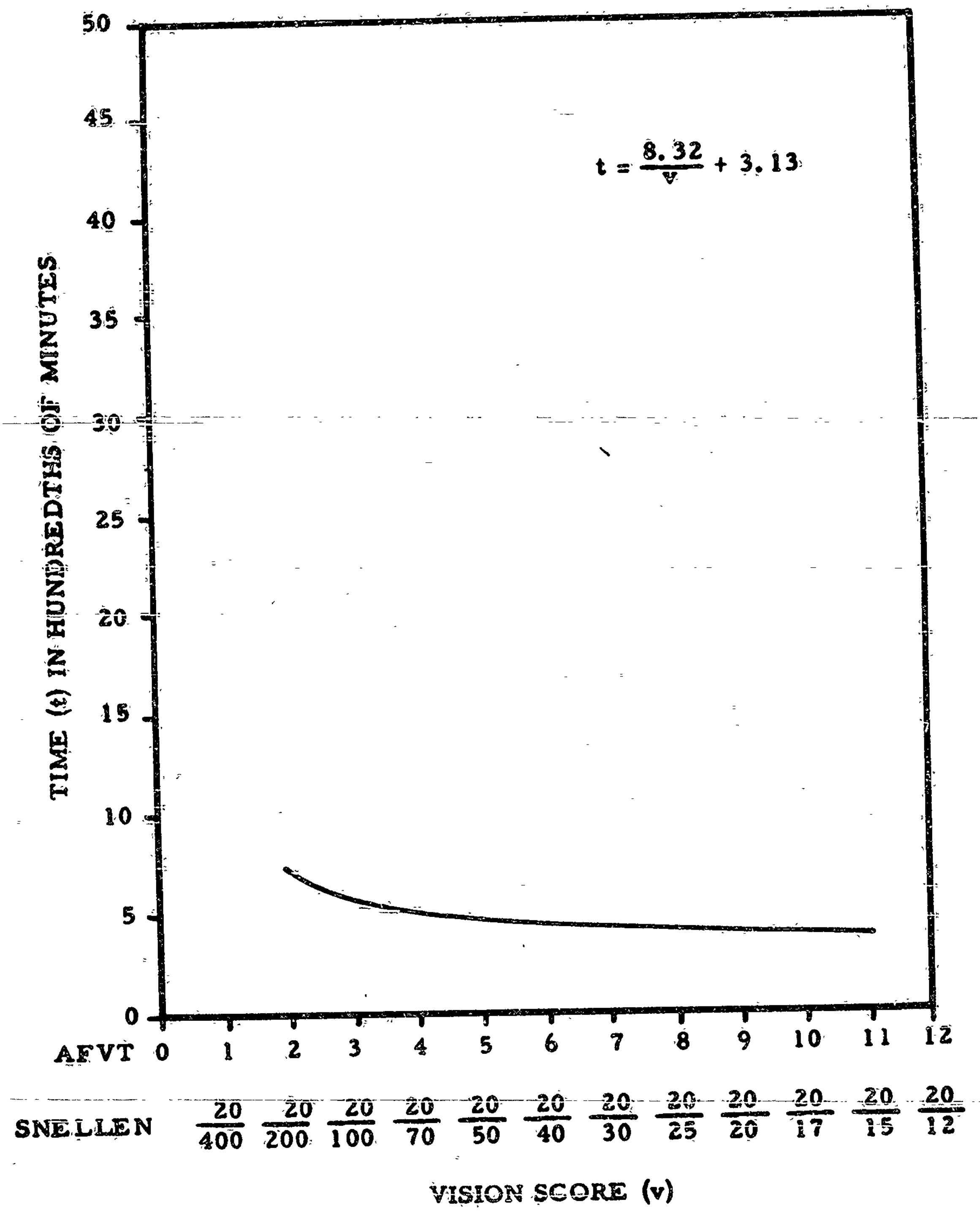

FIG. 31. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERFORMANCE TIME ON DIAL 10.

Curves representing the relationship between near visual acuity score, as determined by the Armed Forces Vision Tester, and performance on the accuracy criterion were developed in essentially the same manner as the time curves. However, mathematical curves were not fitted to the accuracy data. As the purpose of the curves was to determine if the trend of the curves was the same for both criteria, little or no additional information would be derived from fitting mathematical curves to the data. Therefore, free-hand curves were fitted to the composite data for each dial. The resulting performance curves based on the accuracy criterion are presented in Figures 32 through 41.

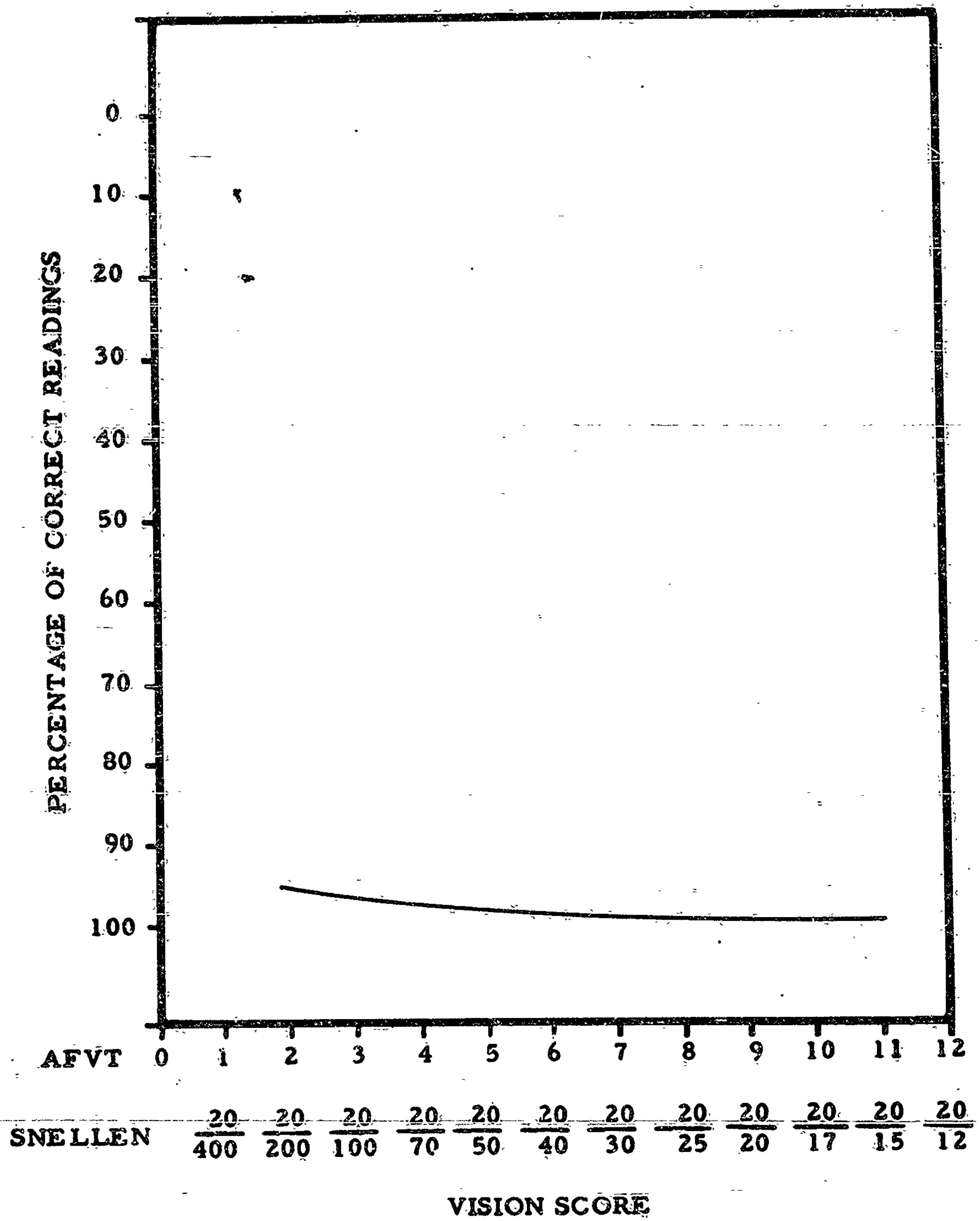

FIG. 32. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 1.

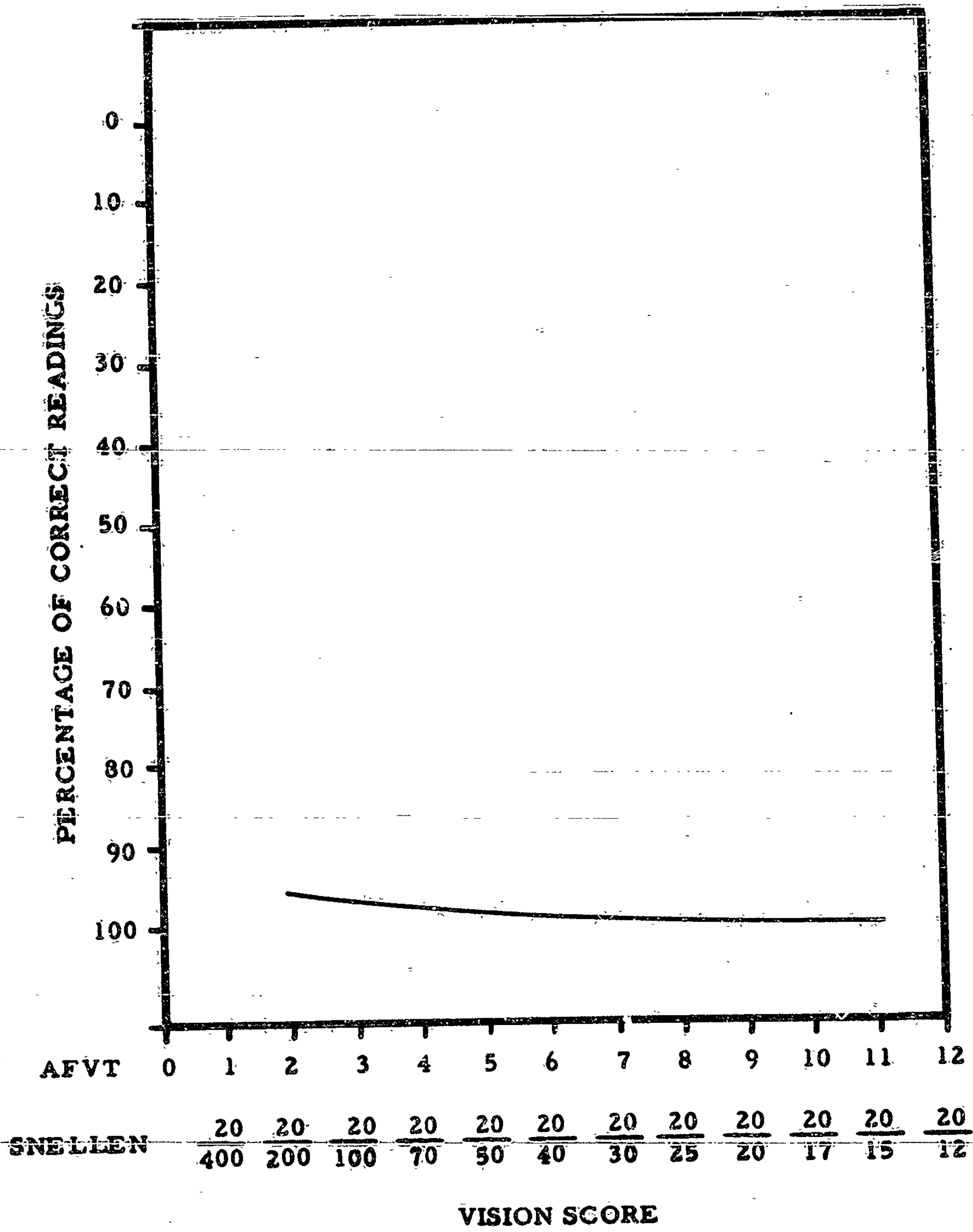

FIG. 33. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 2.

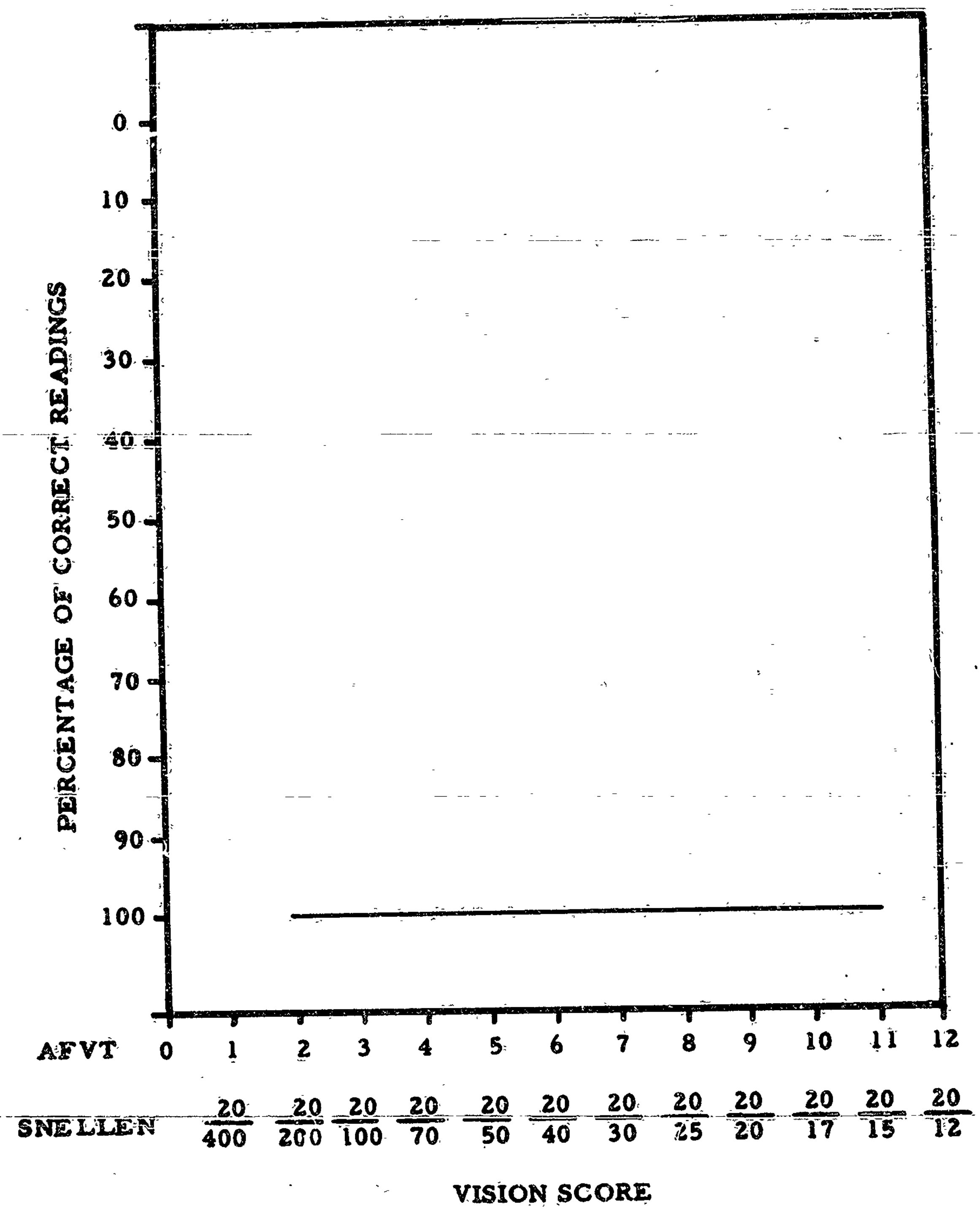

FIG. 34. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 3.

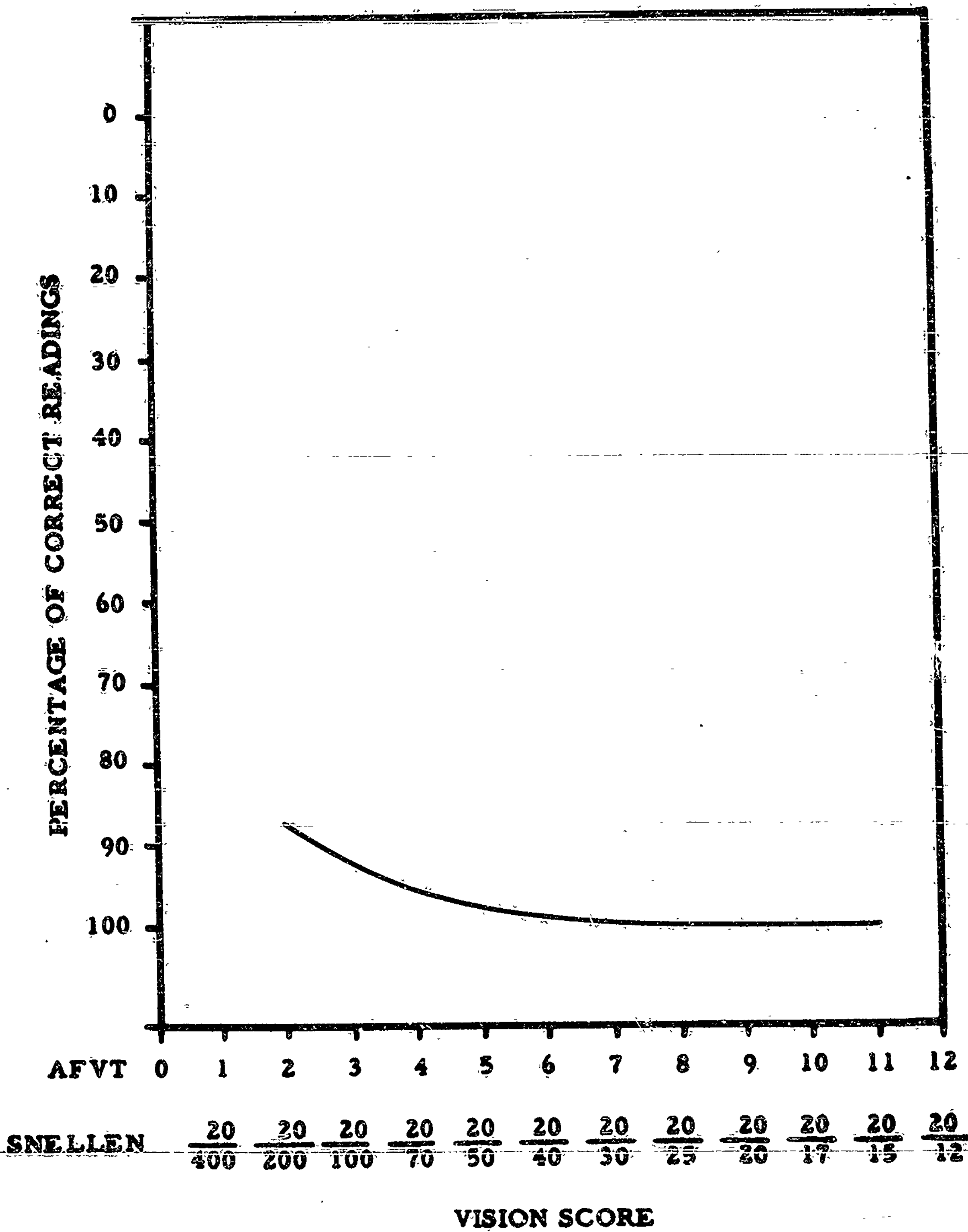

FIG. 35. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 4.

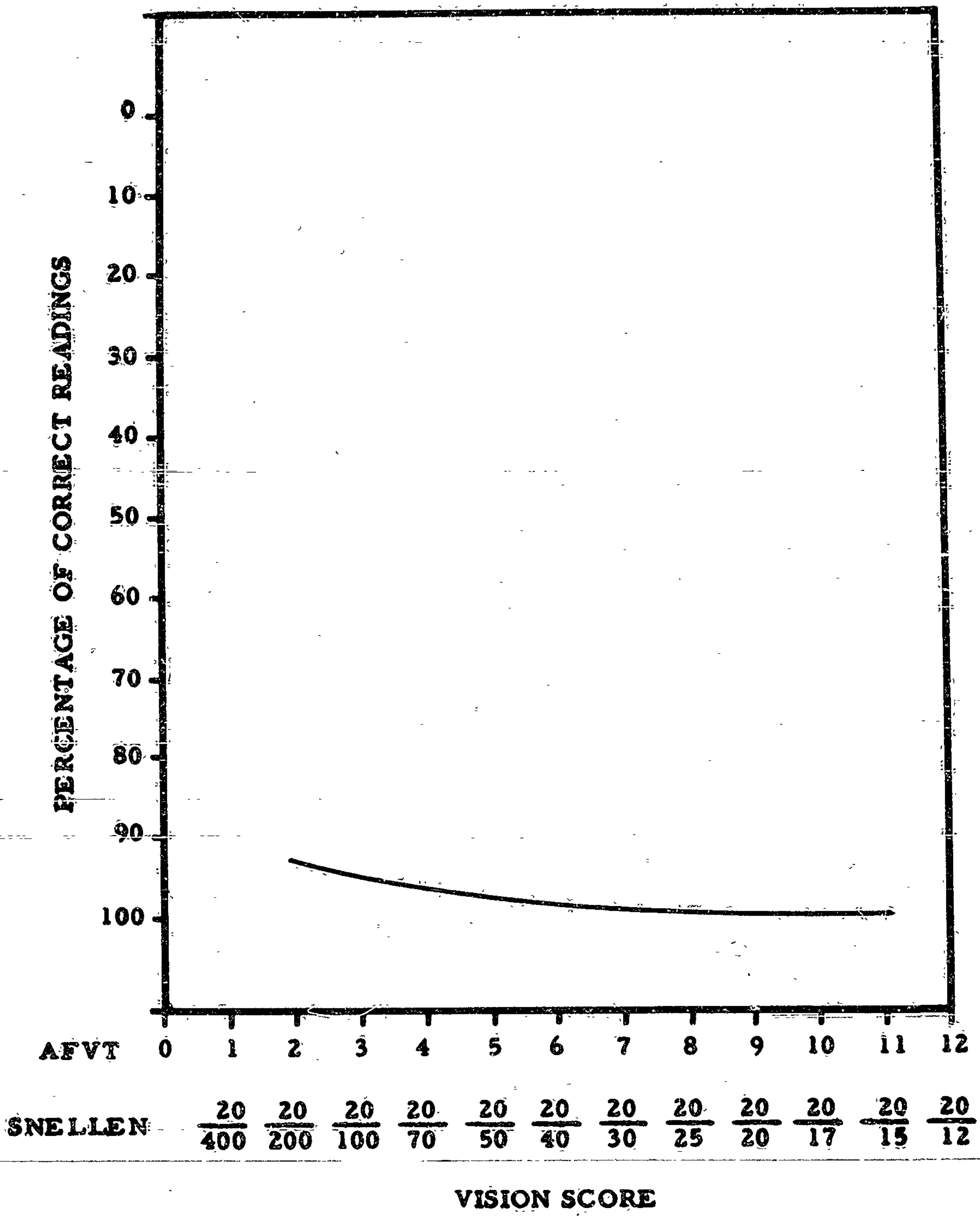

FIG. 36 . RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 5.

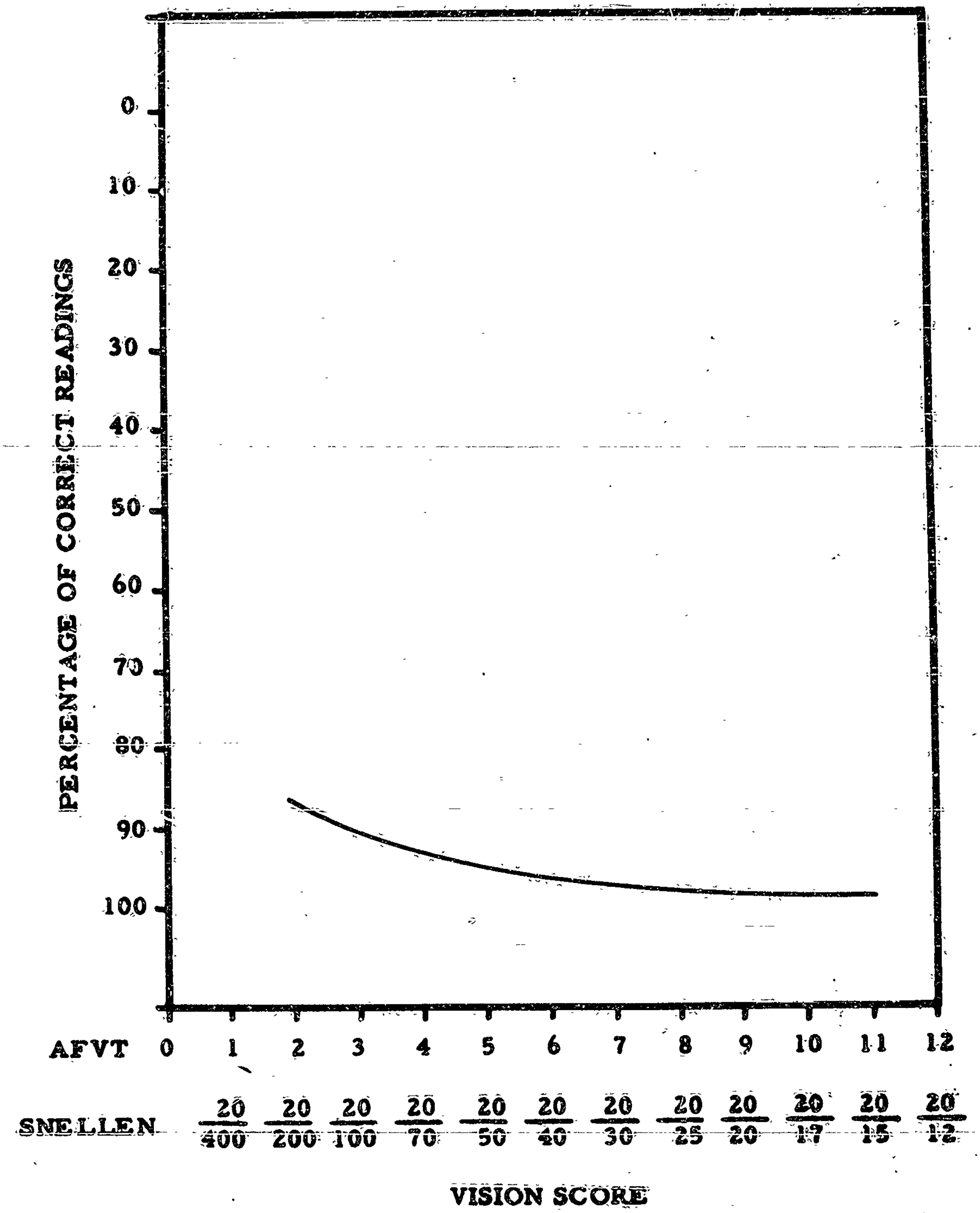

FIG. 37. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 6.

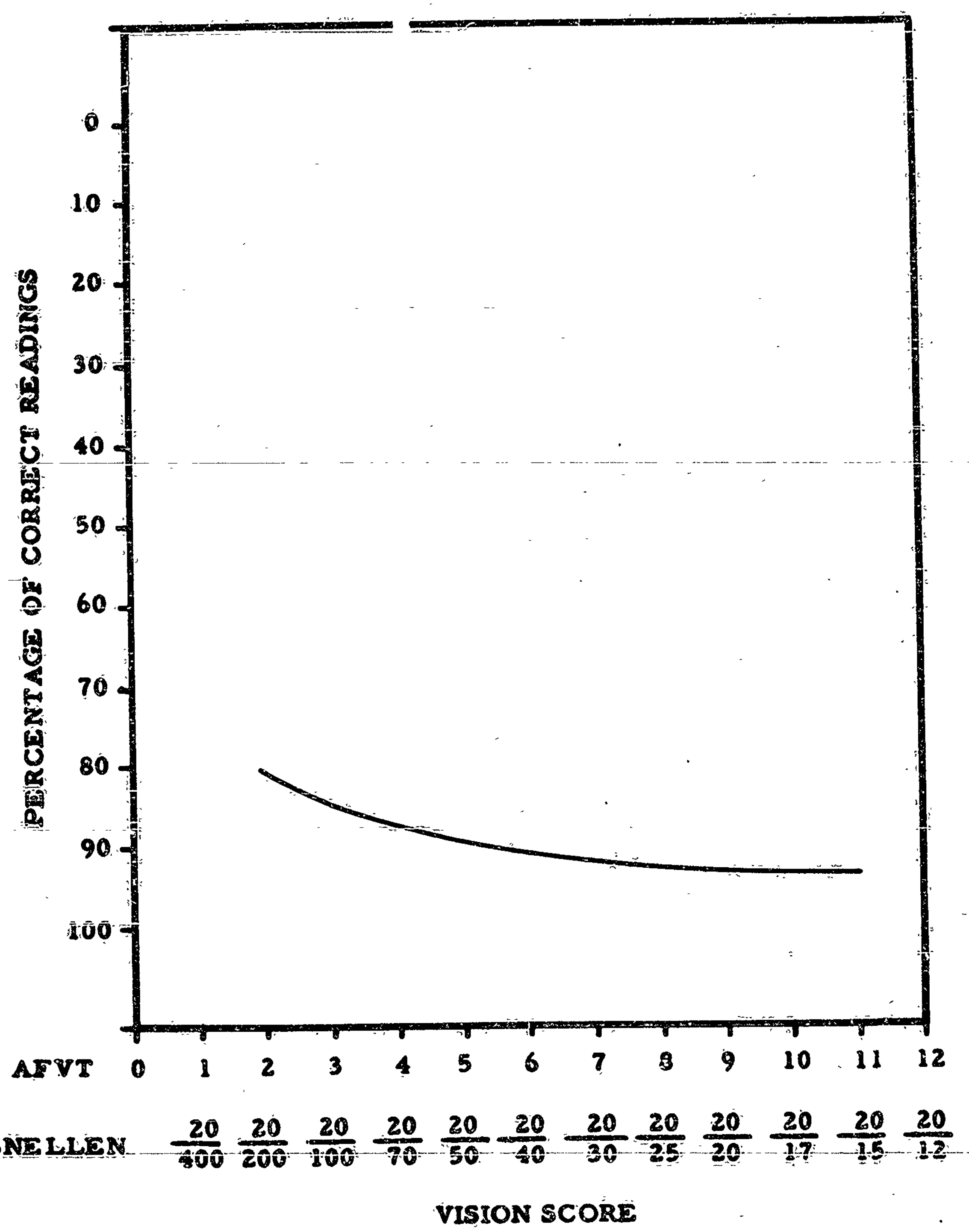

FIG. 38. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 7.

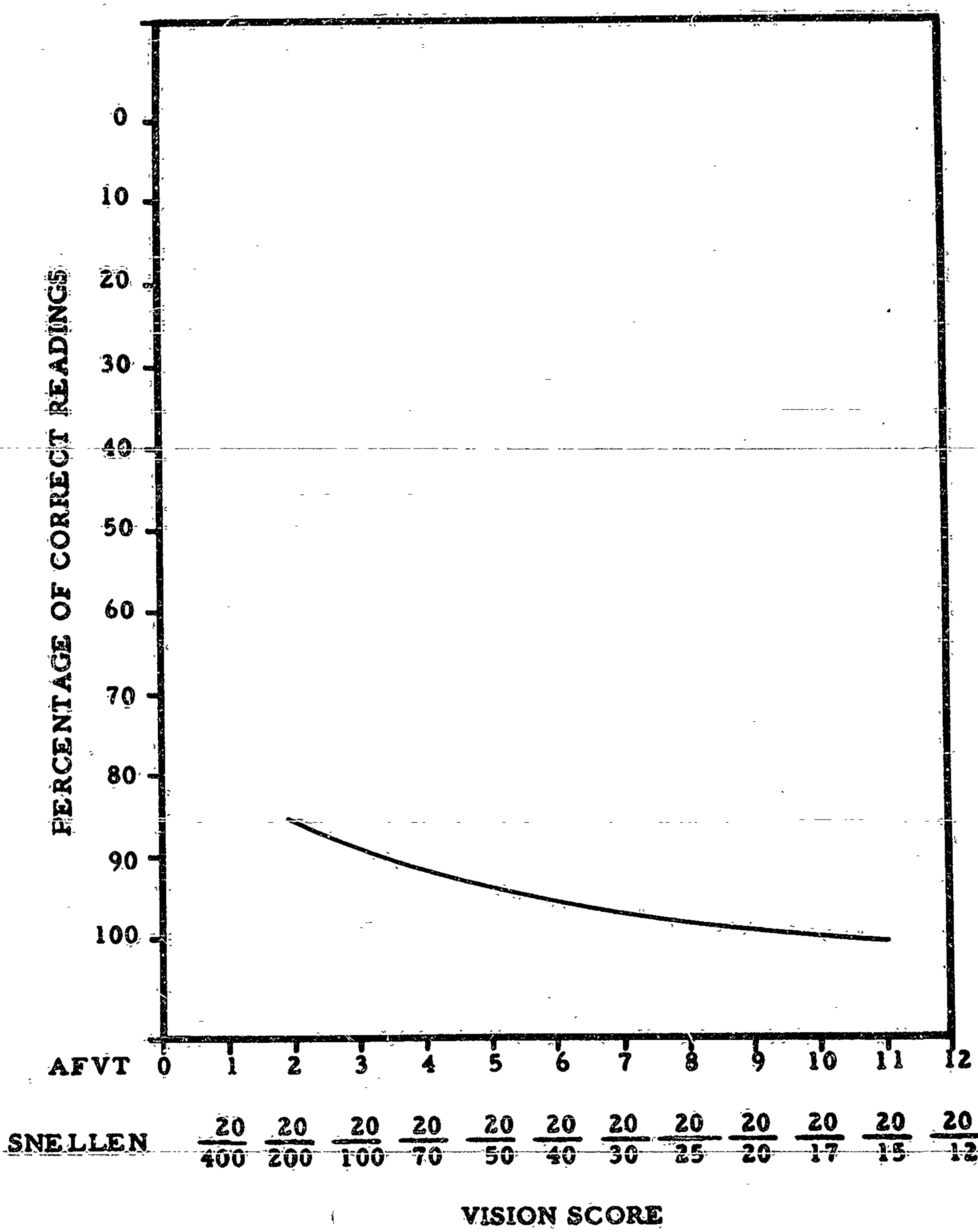

FIG. 39. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 8.

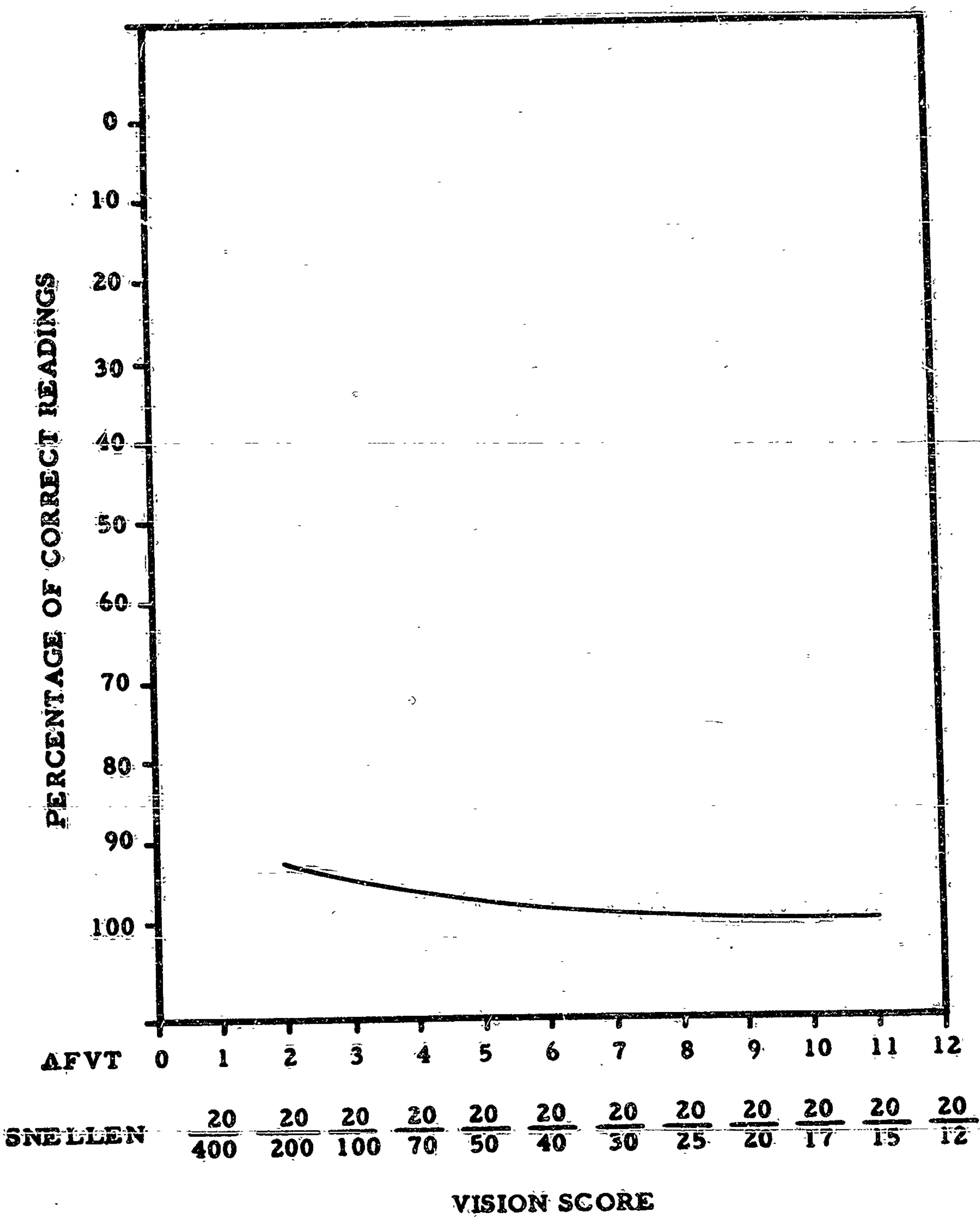

FIG.40 . RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT READINGS ON DIAL 9.

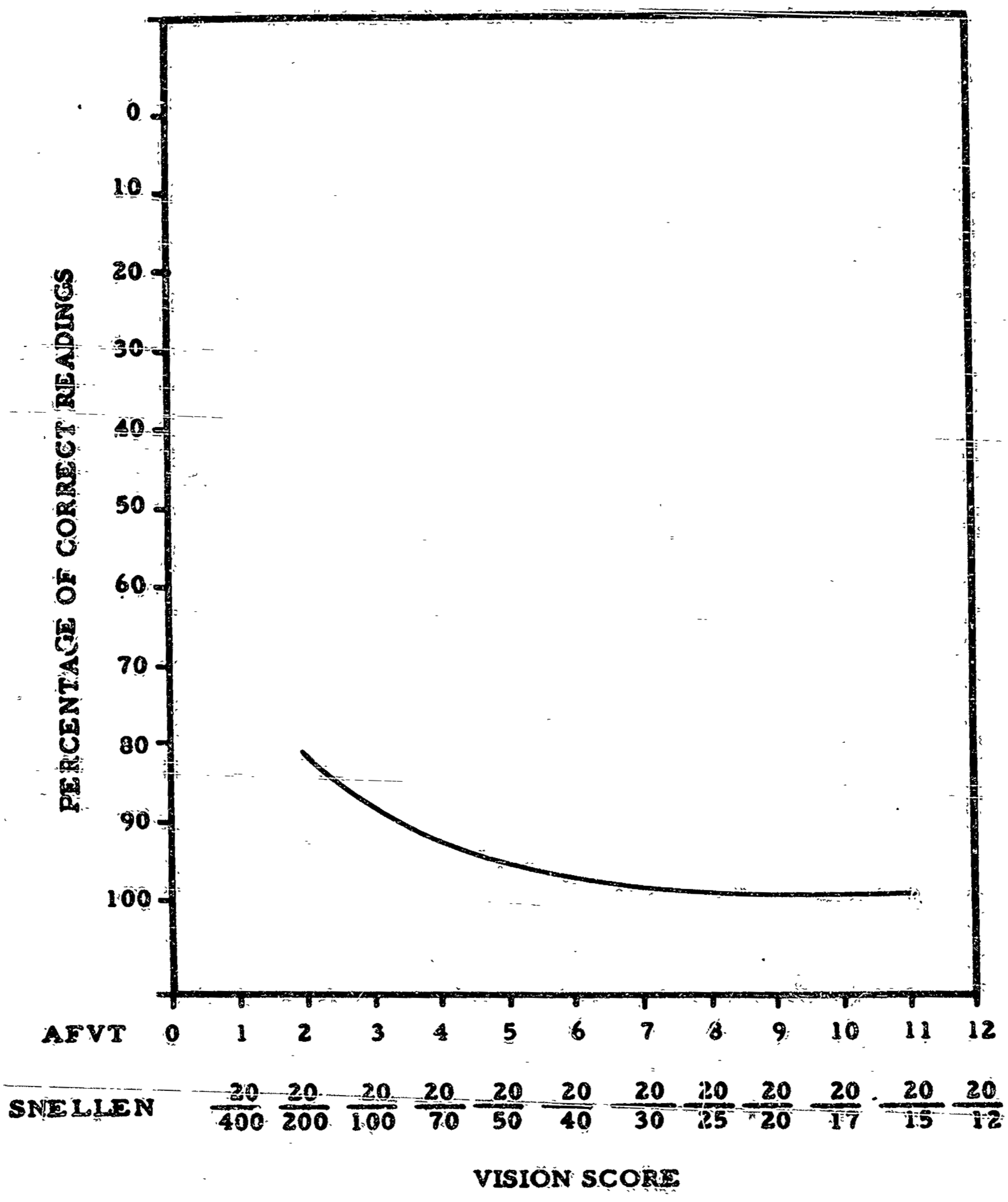

FIG. 41. RELATIONSHIP BETWEEN BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AND PERCENTAGE OF CORRECT FEADINGS ON DIAL 10.

<u>Phase IV.</u> Curves were fitted to the data collected in Phase IV in the same manner as those fitted to the data collected in Phase III. As the same subjects, and the same visual conditions were used in both experiments, the range of vision was the same in both cases. However, instead of a curve fitted to the data for different dials as was the case in Phase III, in Phase IV curves were fitted to the 50 raw averages available for each combination of the 5 levels of illumination and 3 distances. Figures 42 through 56 show the curve fitted to the time data for each condition. All are mathematical curves fitted by the least square inverse curve with the exception of the curve fitted to the data for illumination level 5, distance 3. The inverse and free-hand curves fitted to the data for this condition were quite different. Inspection of the plotted data showed what appeared to be practically a straight - line relationship. Therefore, it was concluded a mathematical function other than the inverse function was needed to show the relationship between vision and performance under those conditions. However, as it had been previously established that free-hand and mathematical curves fitted to the same data are practically identical, it was decided little would be gained by solving for the proper mathematical curve to fit the data. In Figure 56, both the free-hand and inverse curve are shown. Interpretation of this set of data should be made from the free-hand curve.

The accuracy curves for each combination of illumination and distance are shown in Figures 57 through 71.

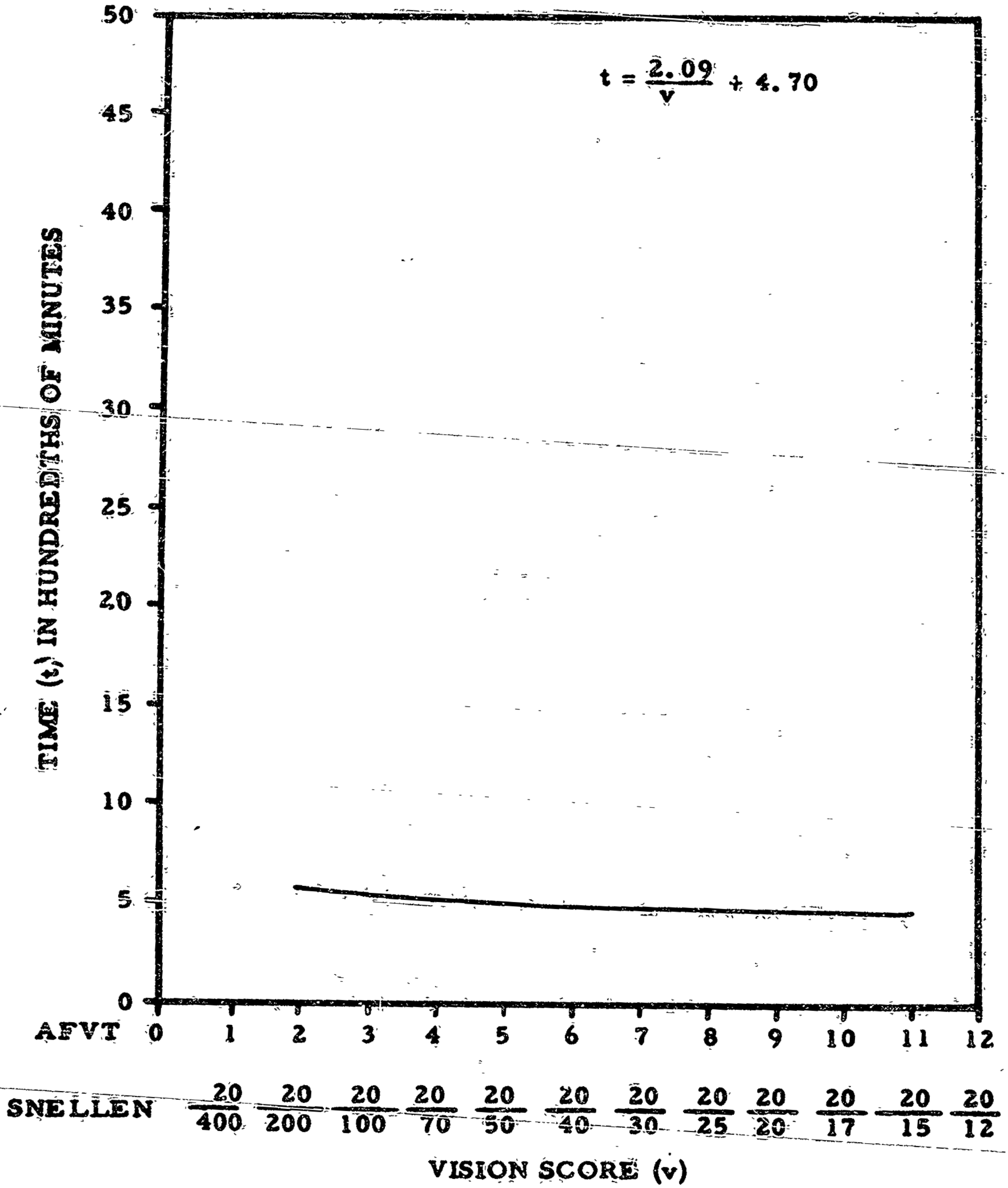

FIG. 42. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 1, DISTANCE 1.

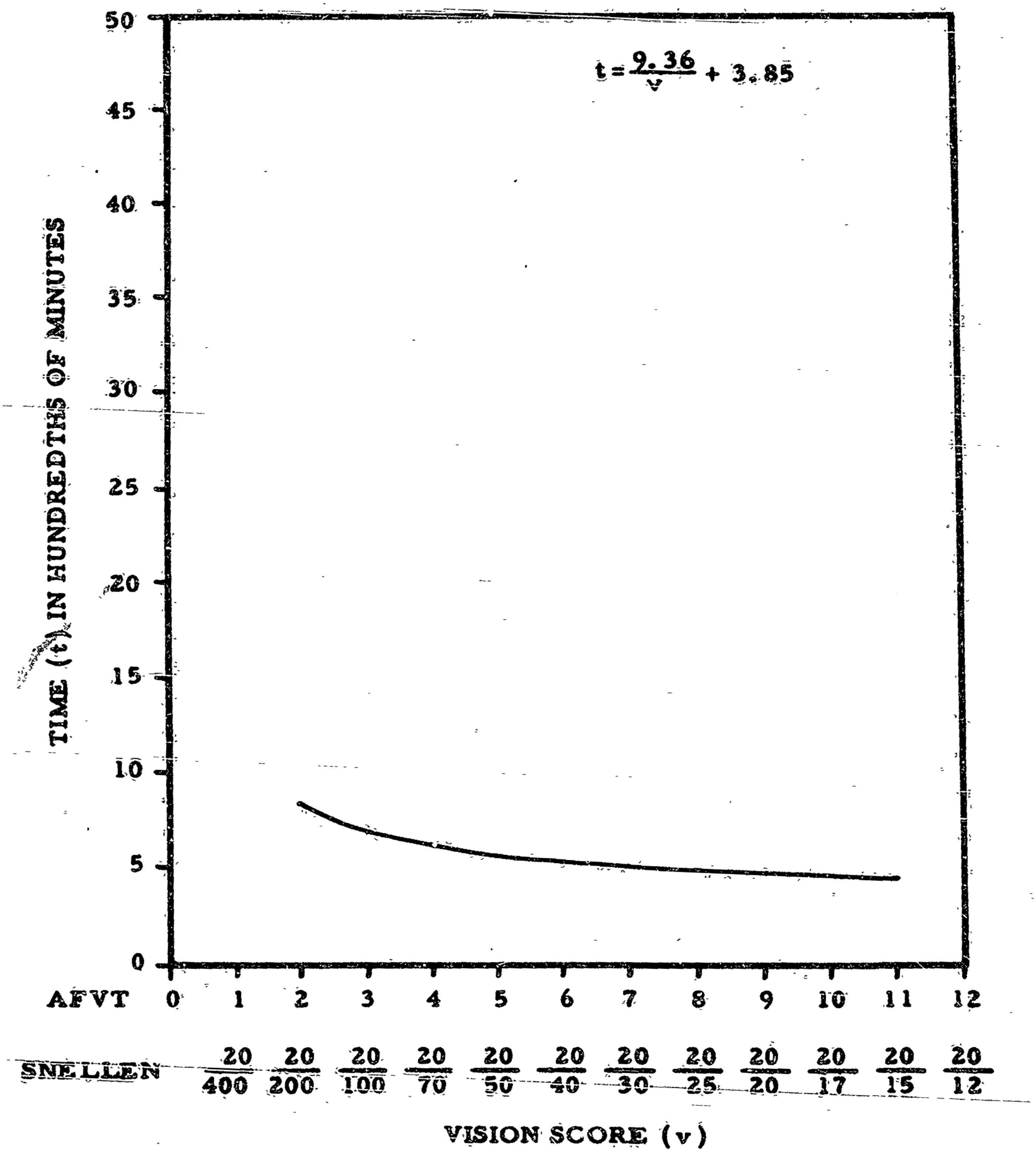

FIG. 43. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 1, DISTANCE 2.

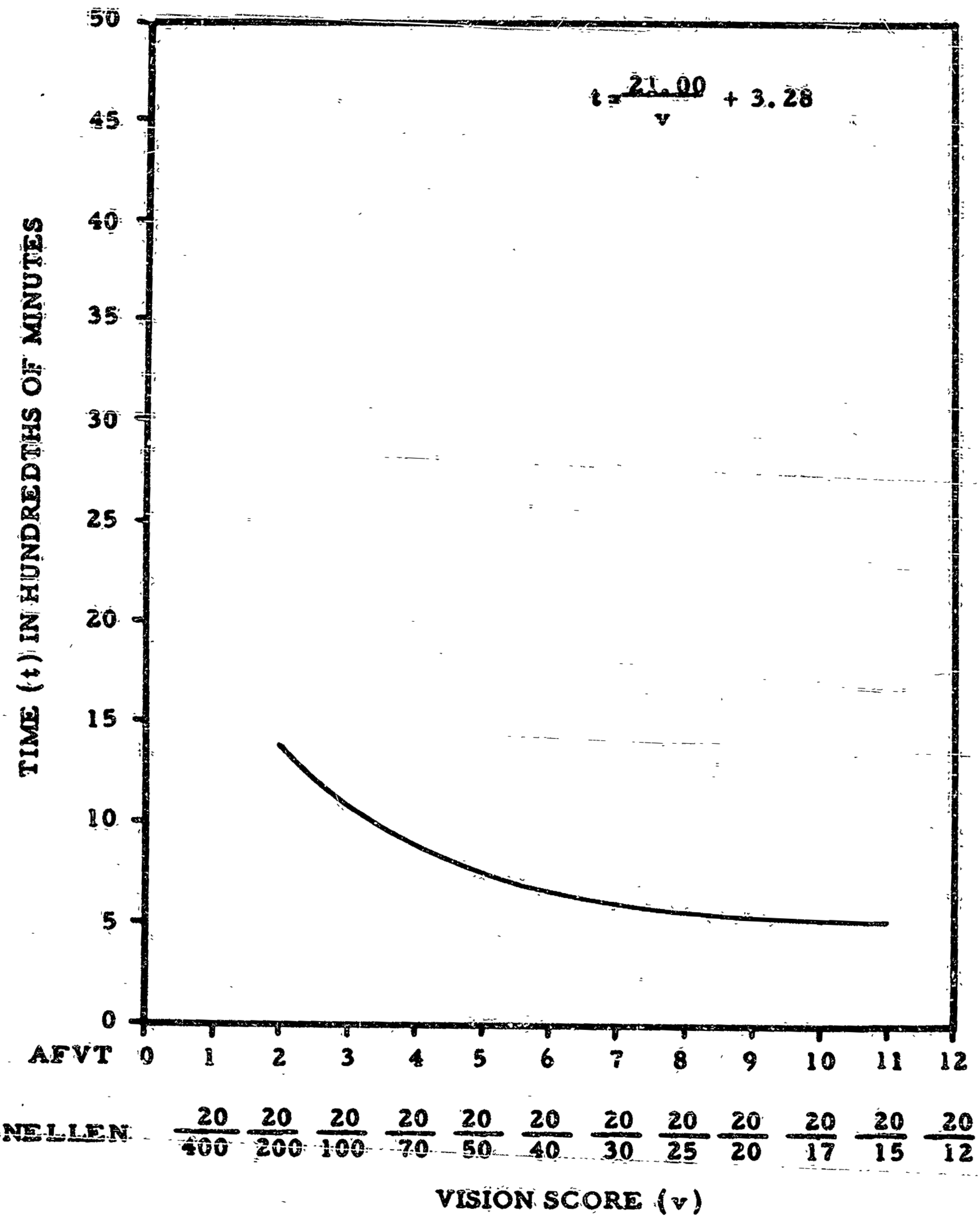

FIG. 44. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 1, DISTANCE 3.

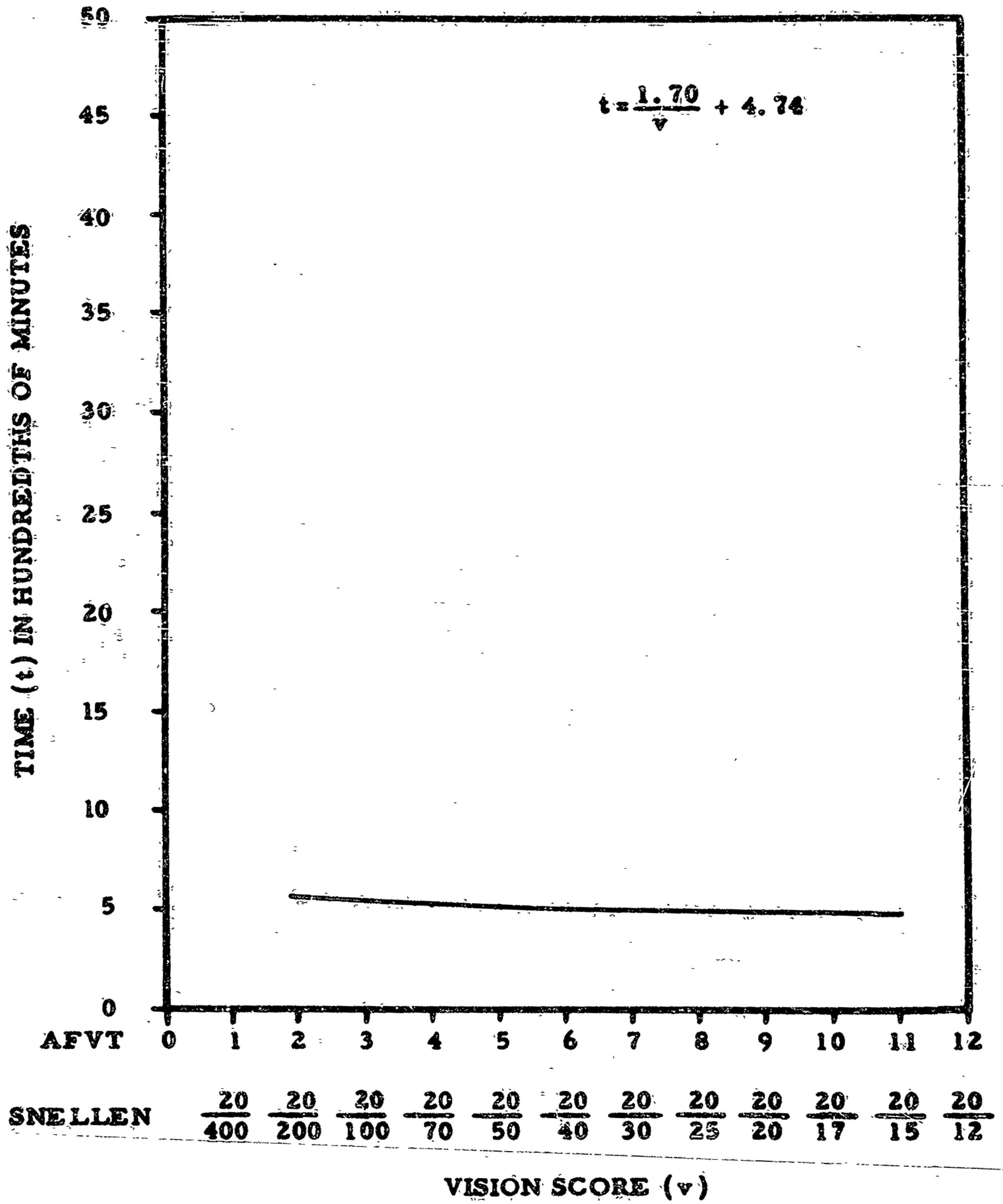

FIG. 45. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 2, DISTANCE 1.

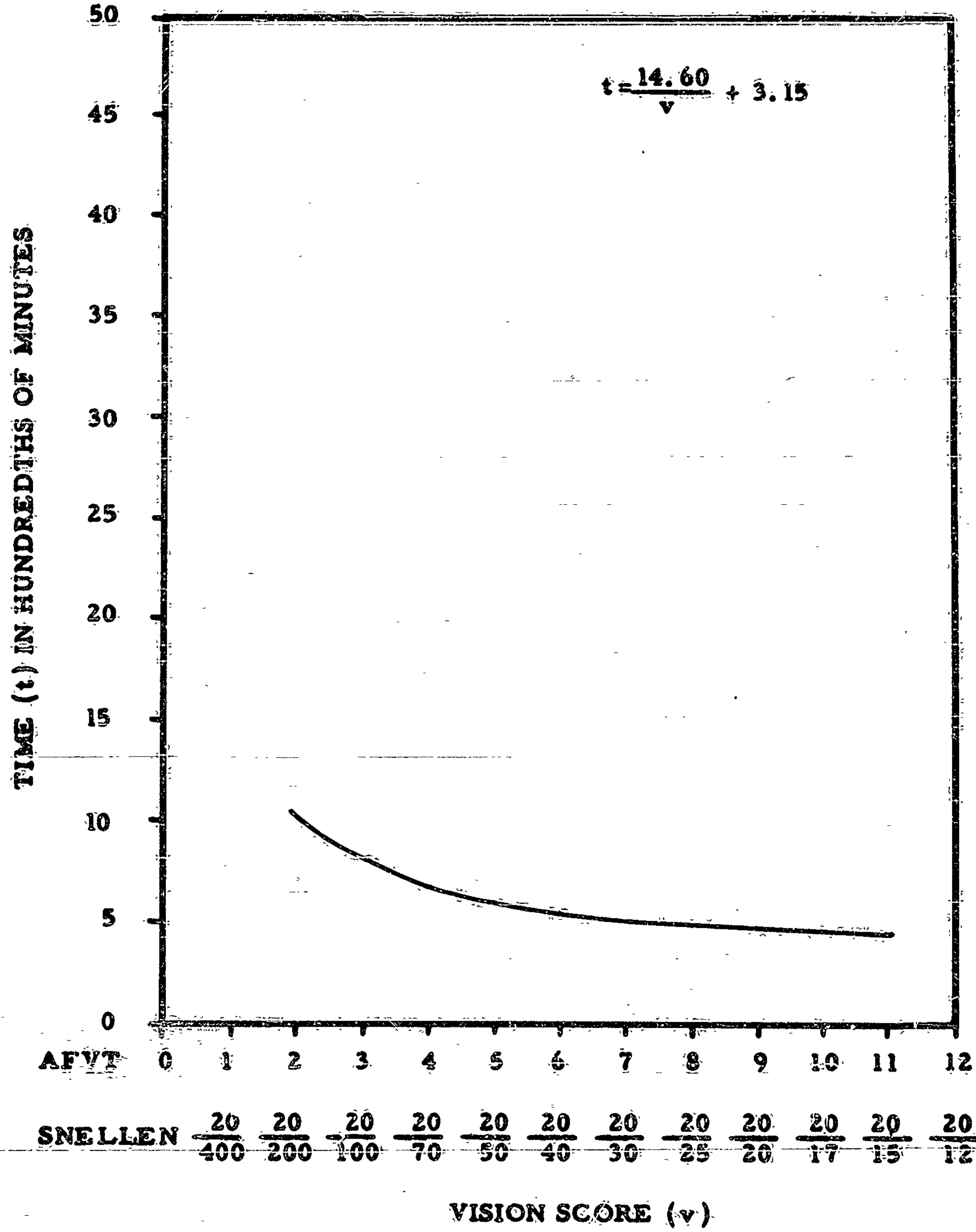

FIG. 46. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 2, DISTANCE 2.

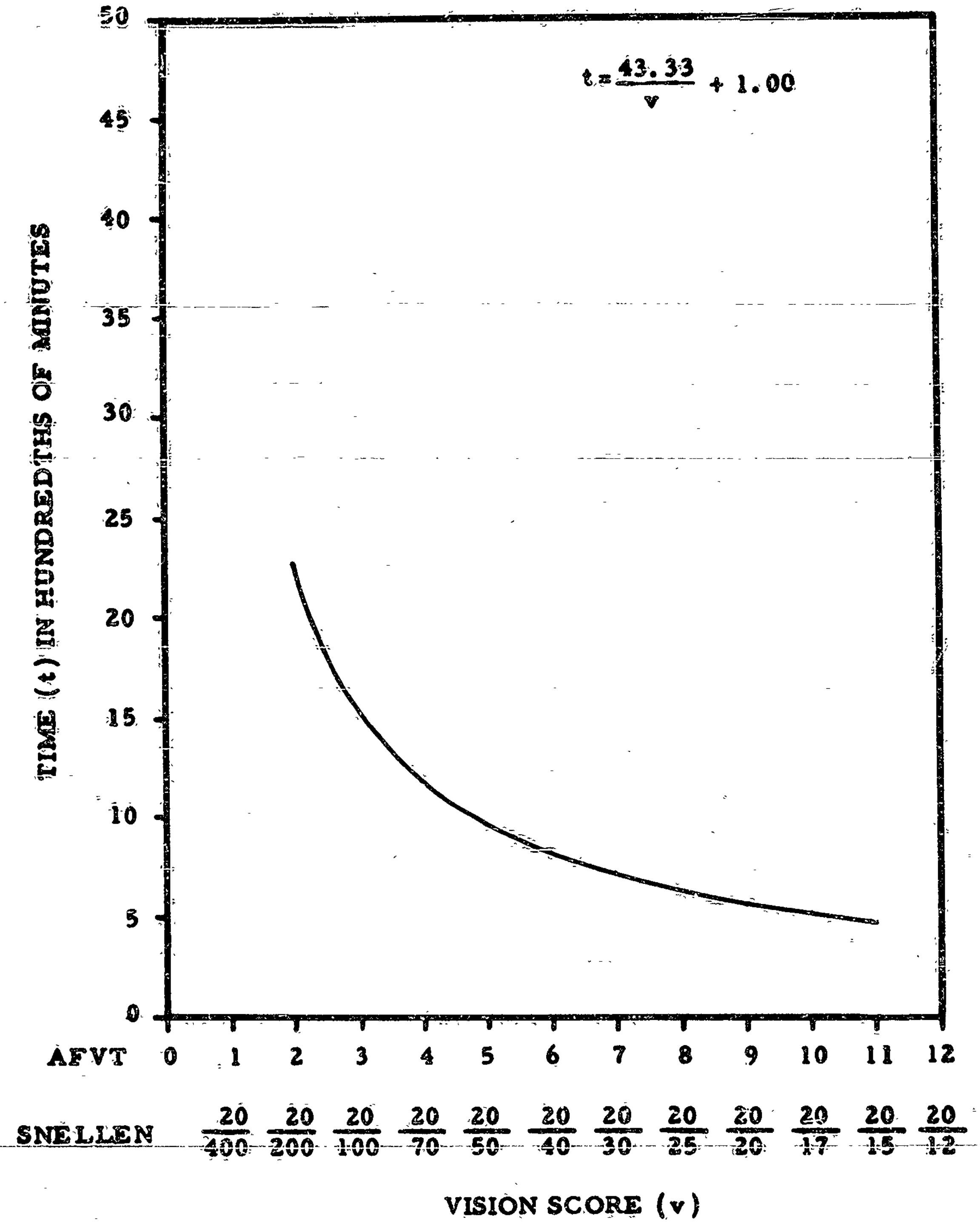

FIG. 47. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 2, DISTANCE 3.

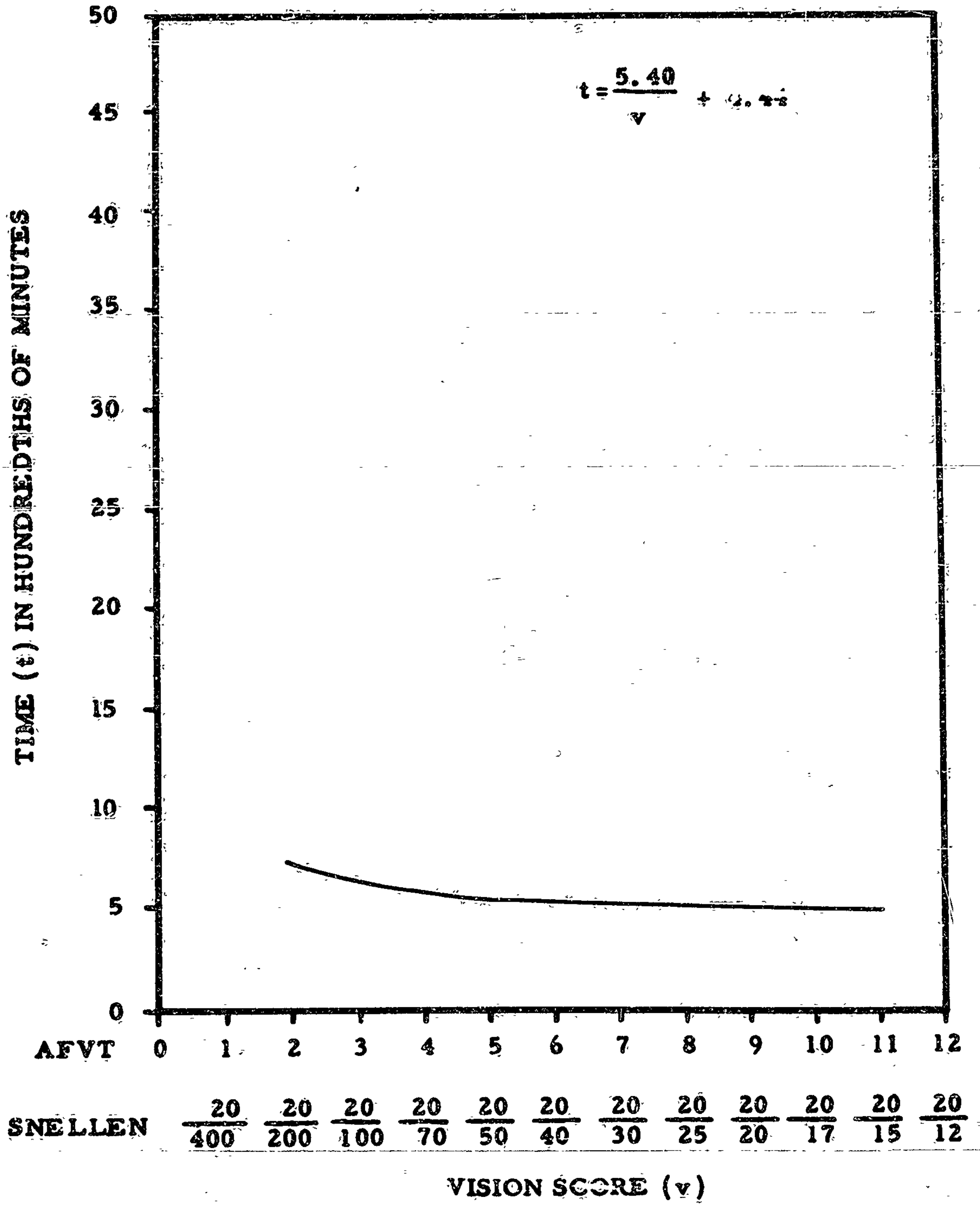

FIG. 48. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 3, DISTANCE 1.

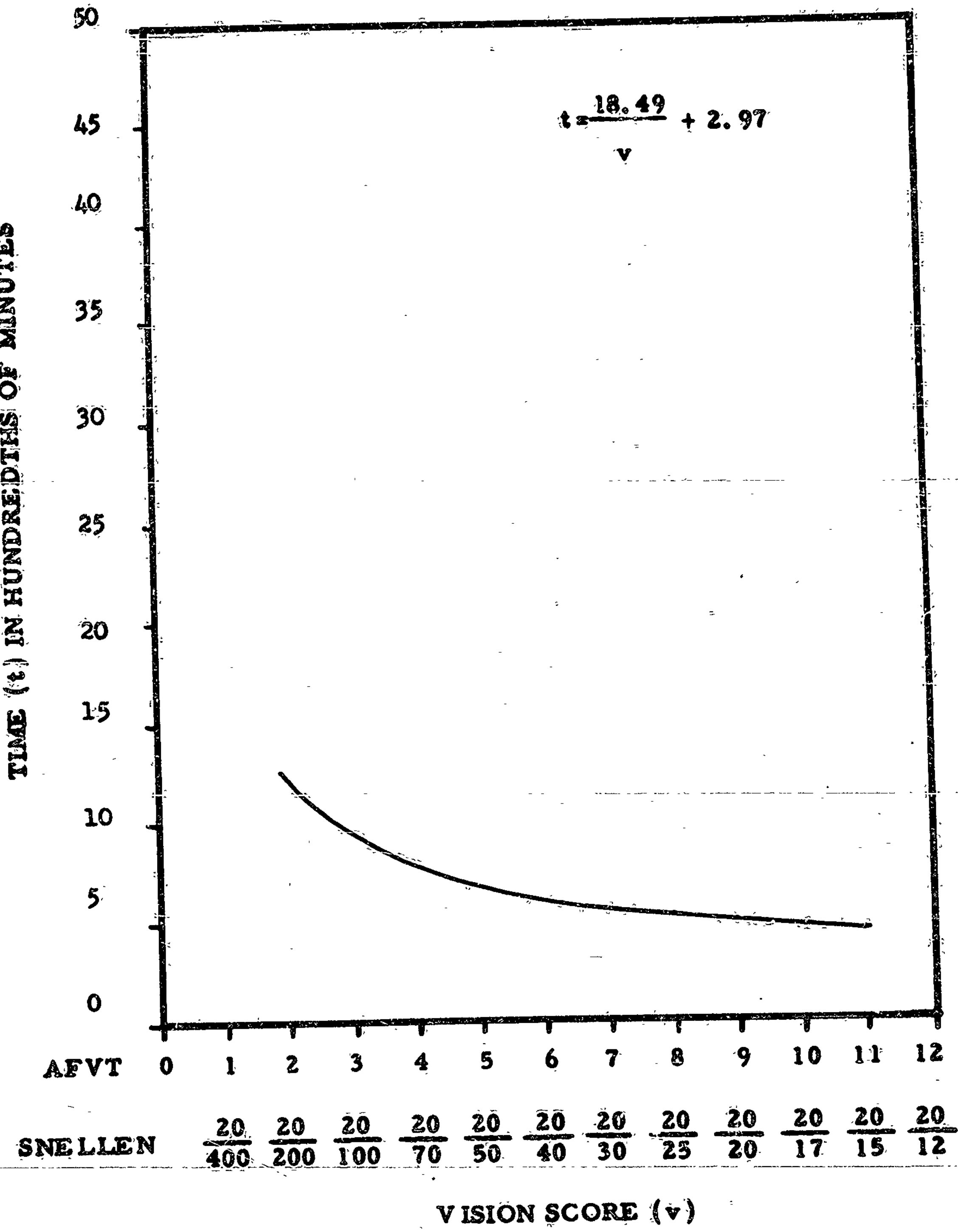

FIG. 49. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 3, DISTANCE 2.

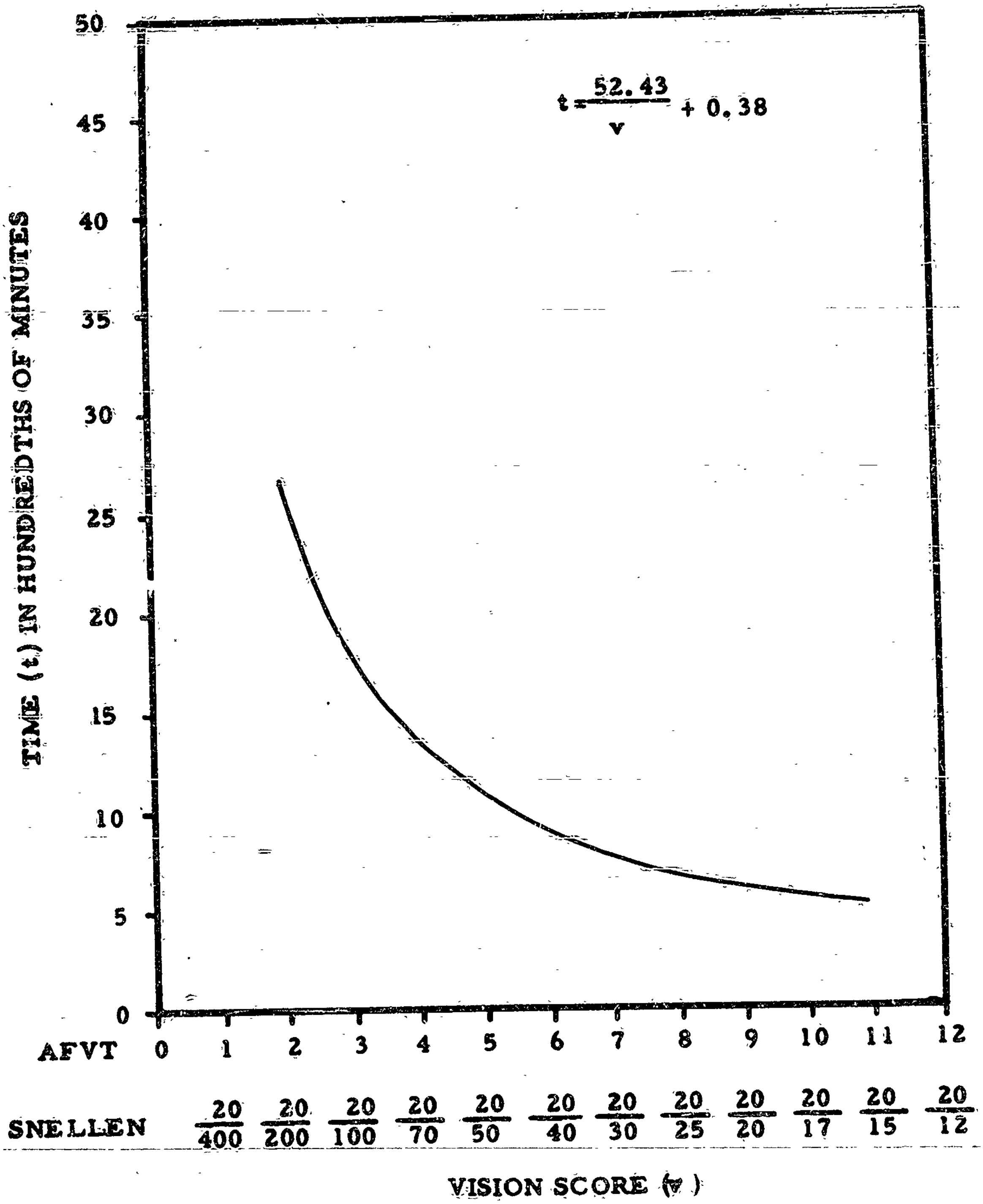

FIG. 50. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 3, DISTANCE 3.

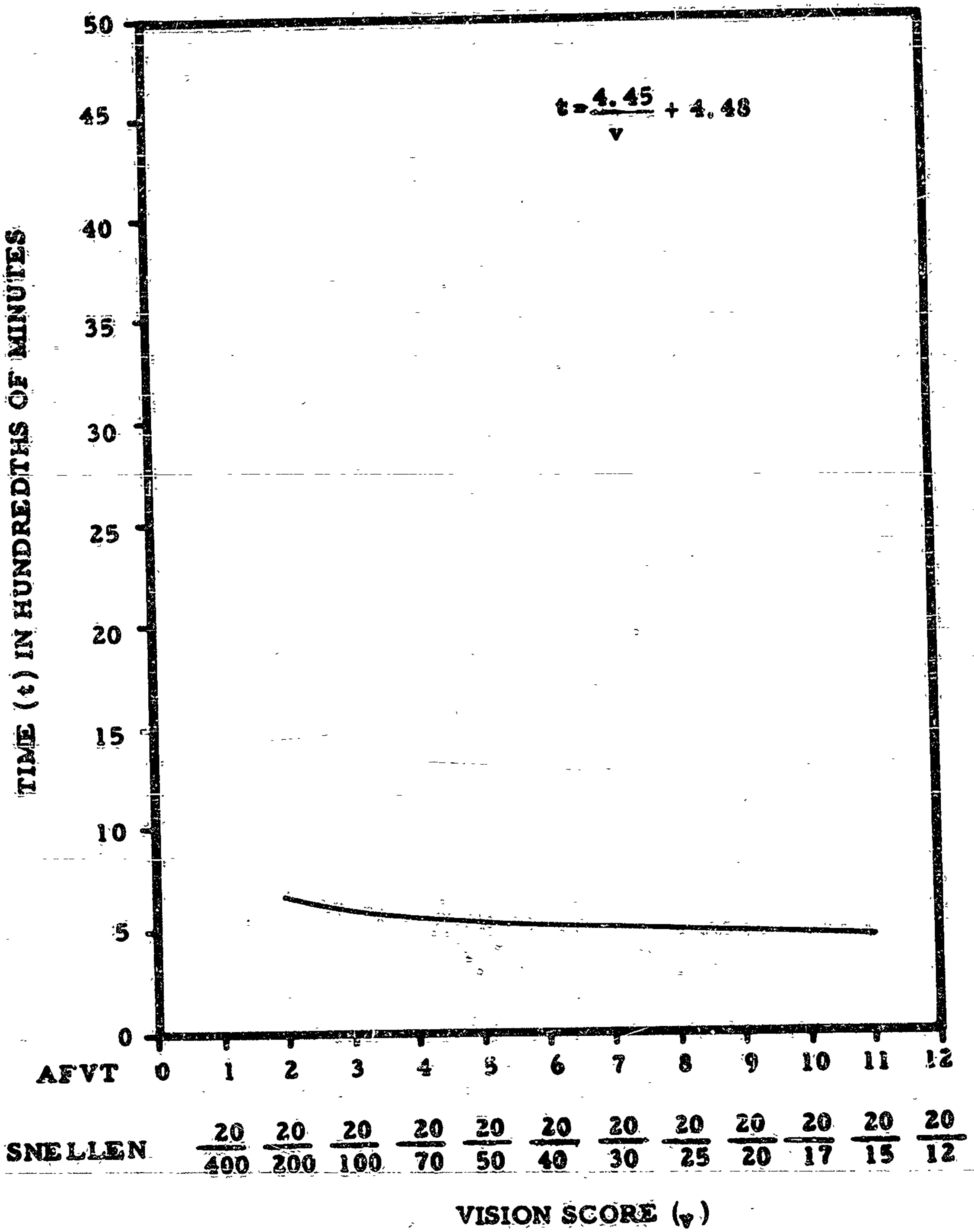

FIG. 51, RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 4 DISTANCE 1.

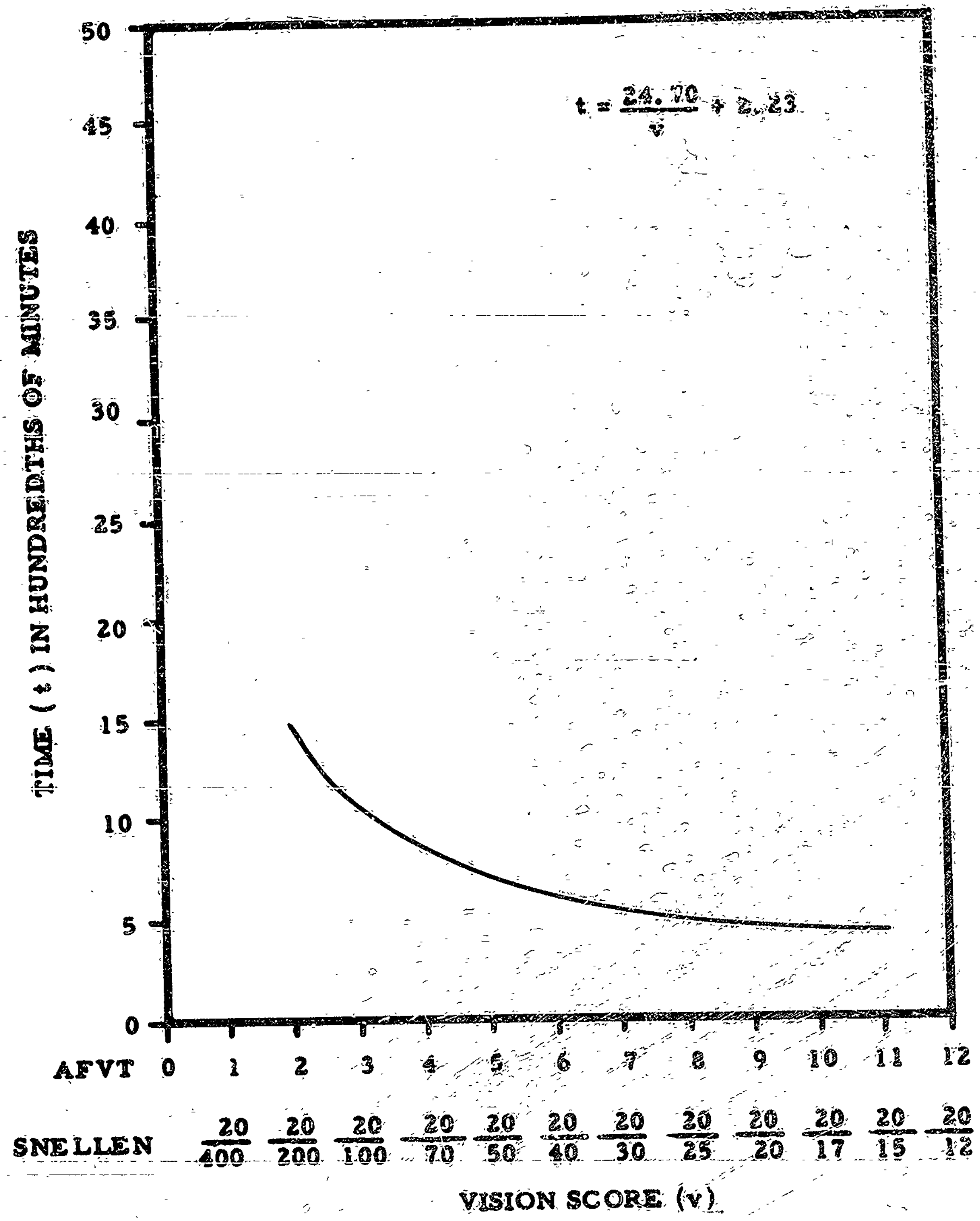

FIG. 52. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 4, DISTANCE 2.

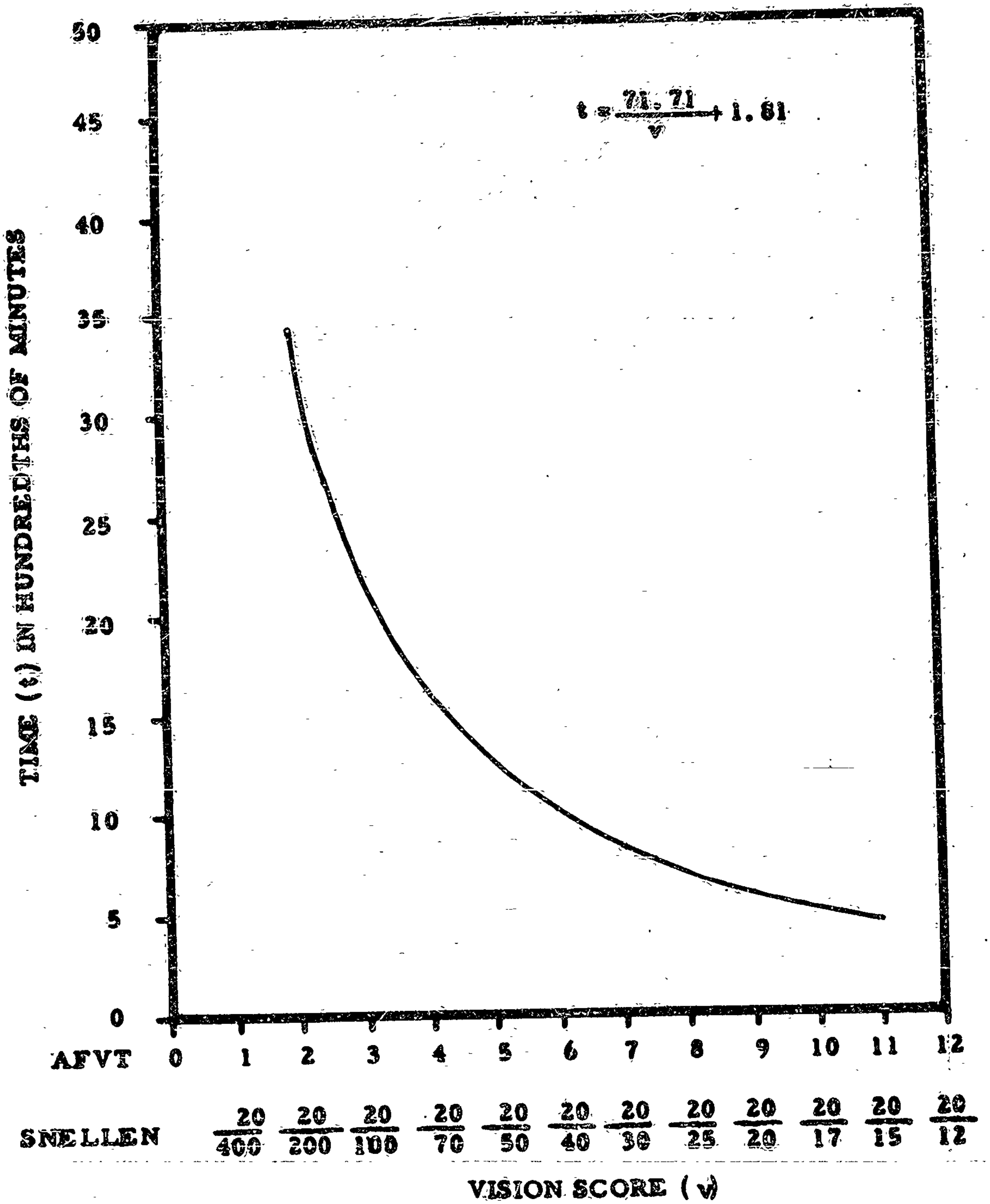

FIG. 53. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 4 DISTANCE 3.

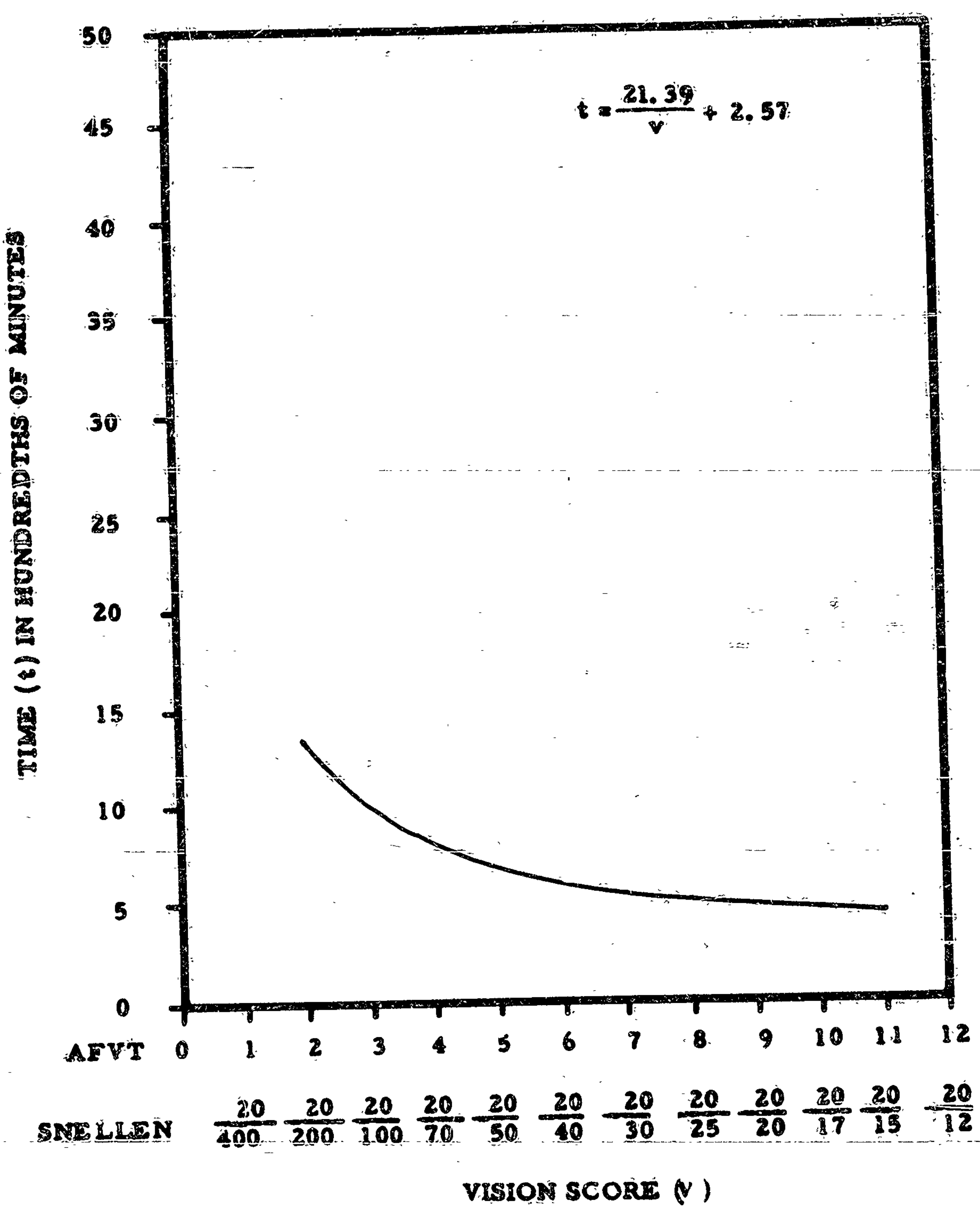

FIG. 54. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 5, DISTANCE 1.

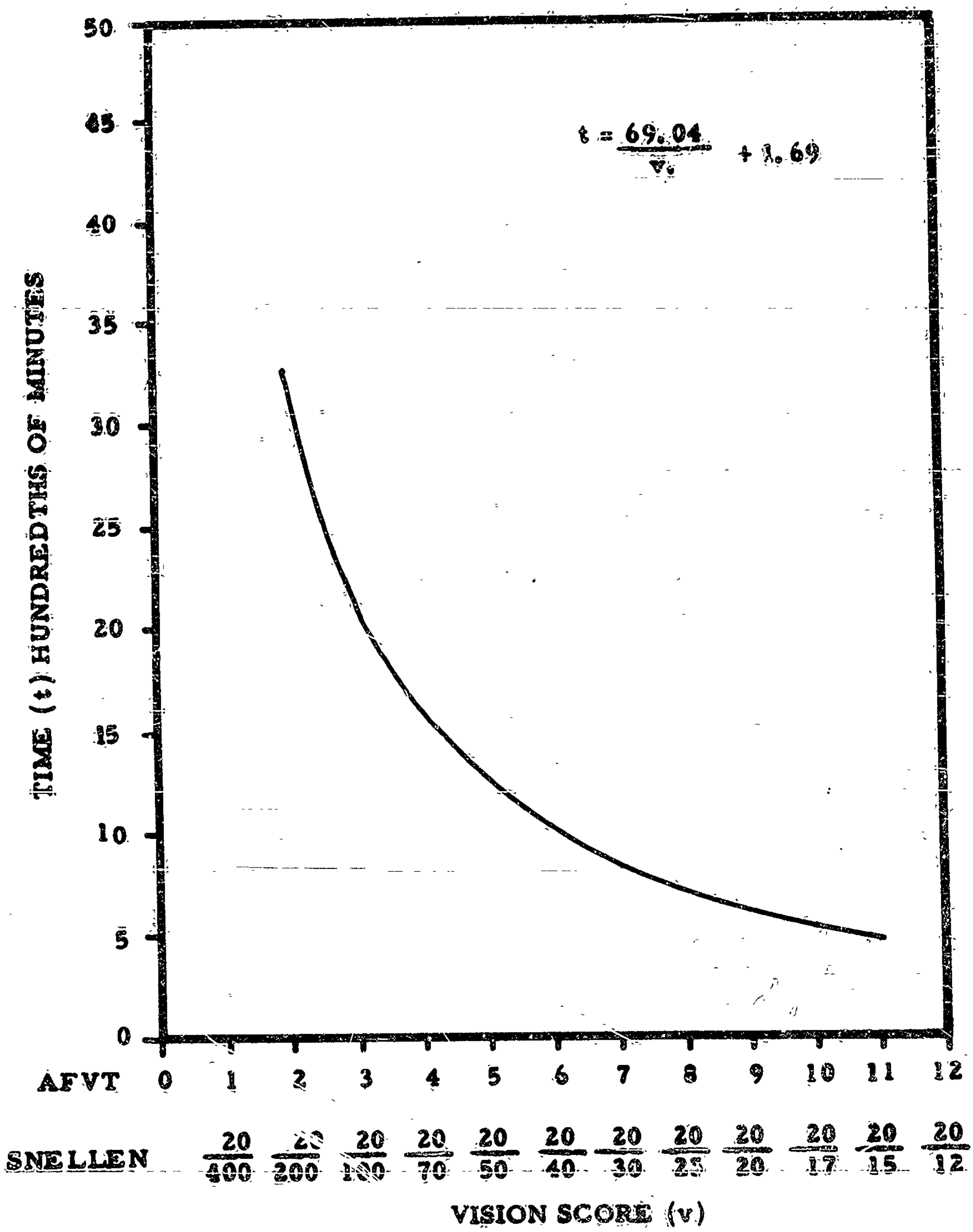

FIG. 55. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 5, DISTANCE 2.

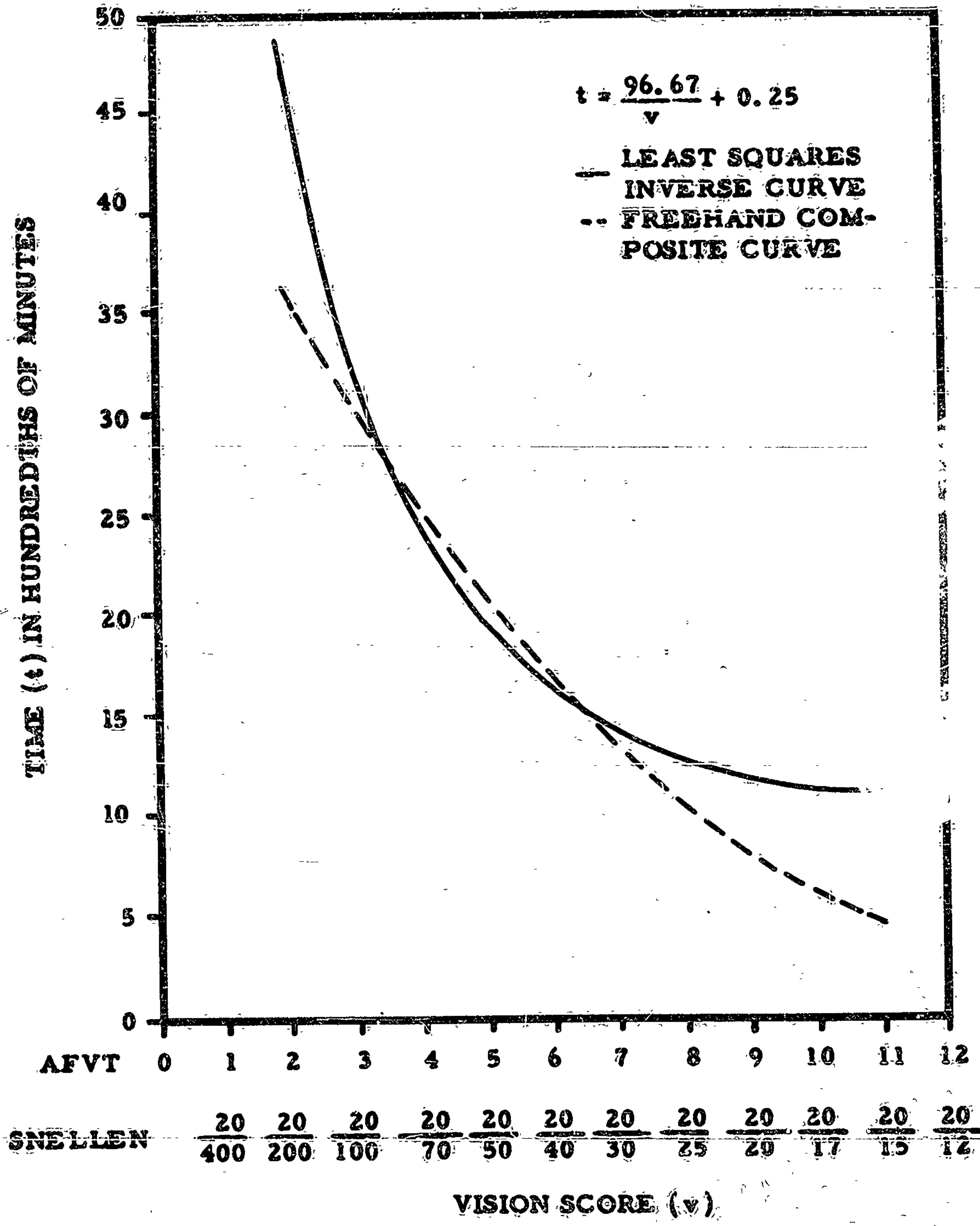

FIG. 56. RELATIONSHIP BETWEEN TIME PERFORMANCE AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 5, DISTANCE 3.

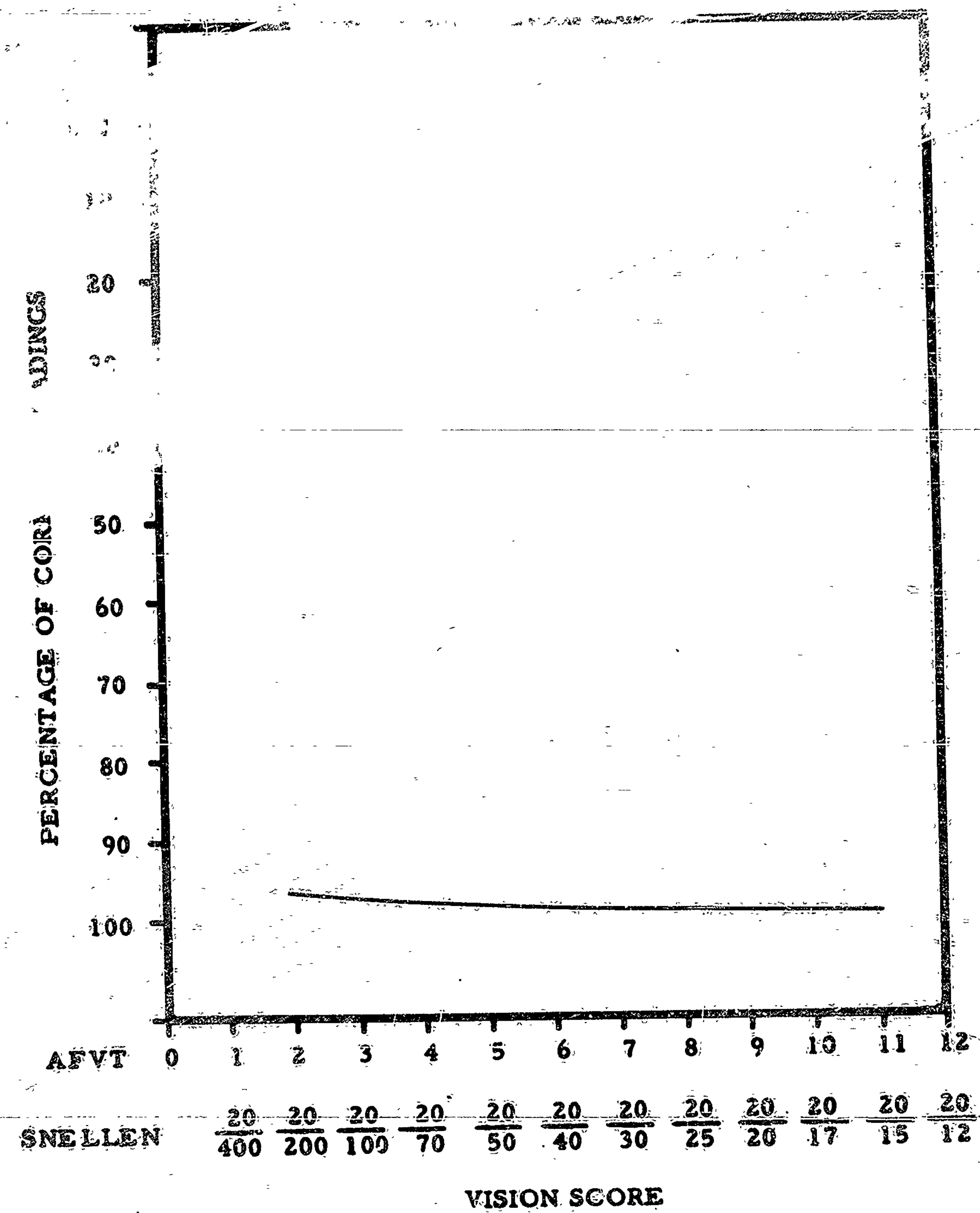

FIG. 57. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 1, DISTANCE 1.

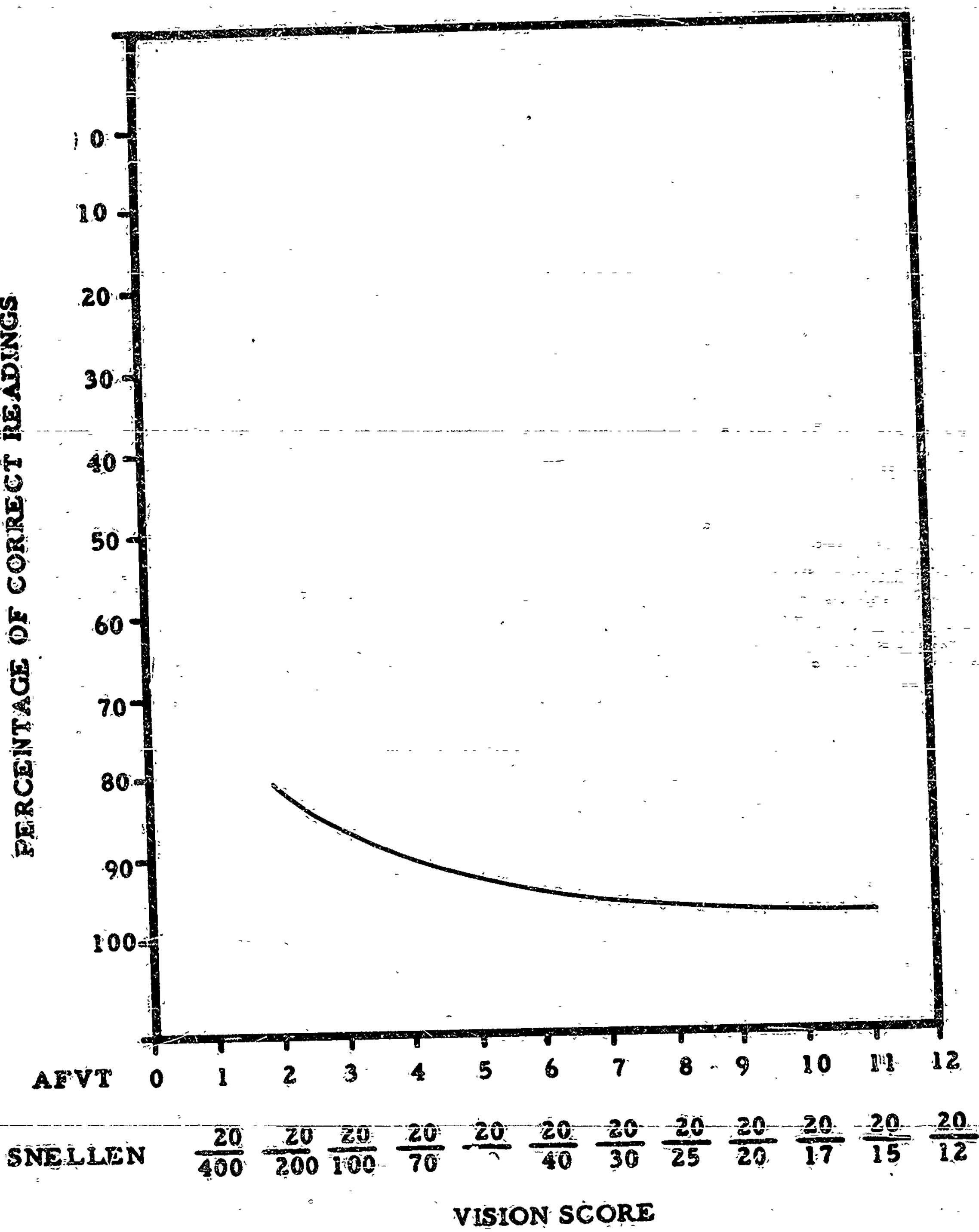

FIG. 58. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 1, DISTANCE 2.

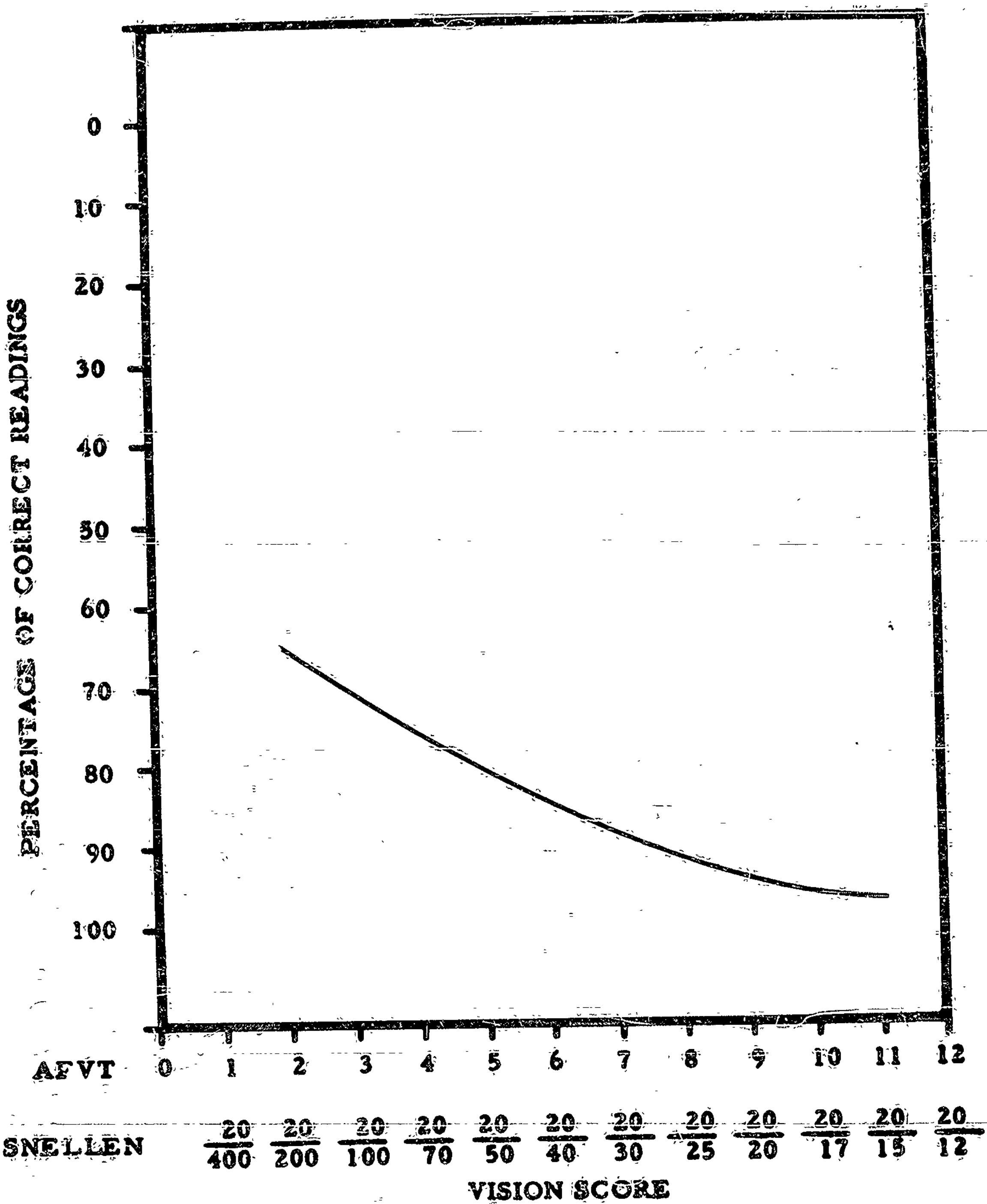

FIG. 59. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 1, DISTANCE 3.

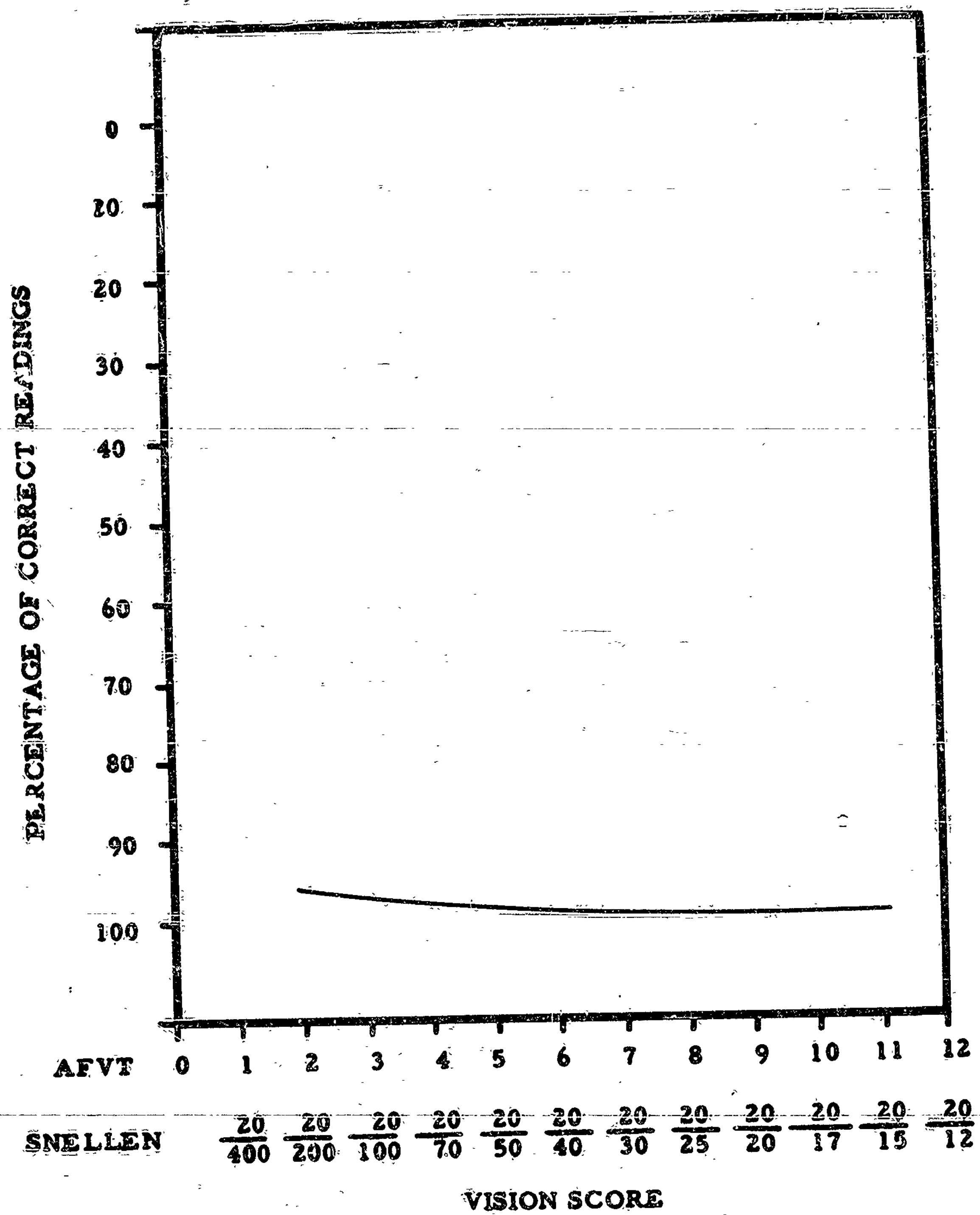

FIG.60. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 2, DISTANCE 1.

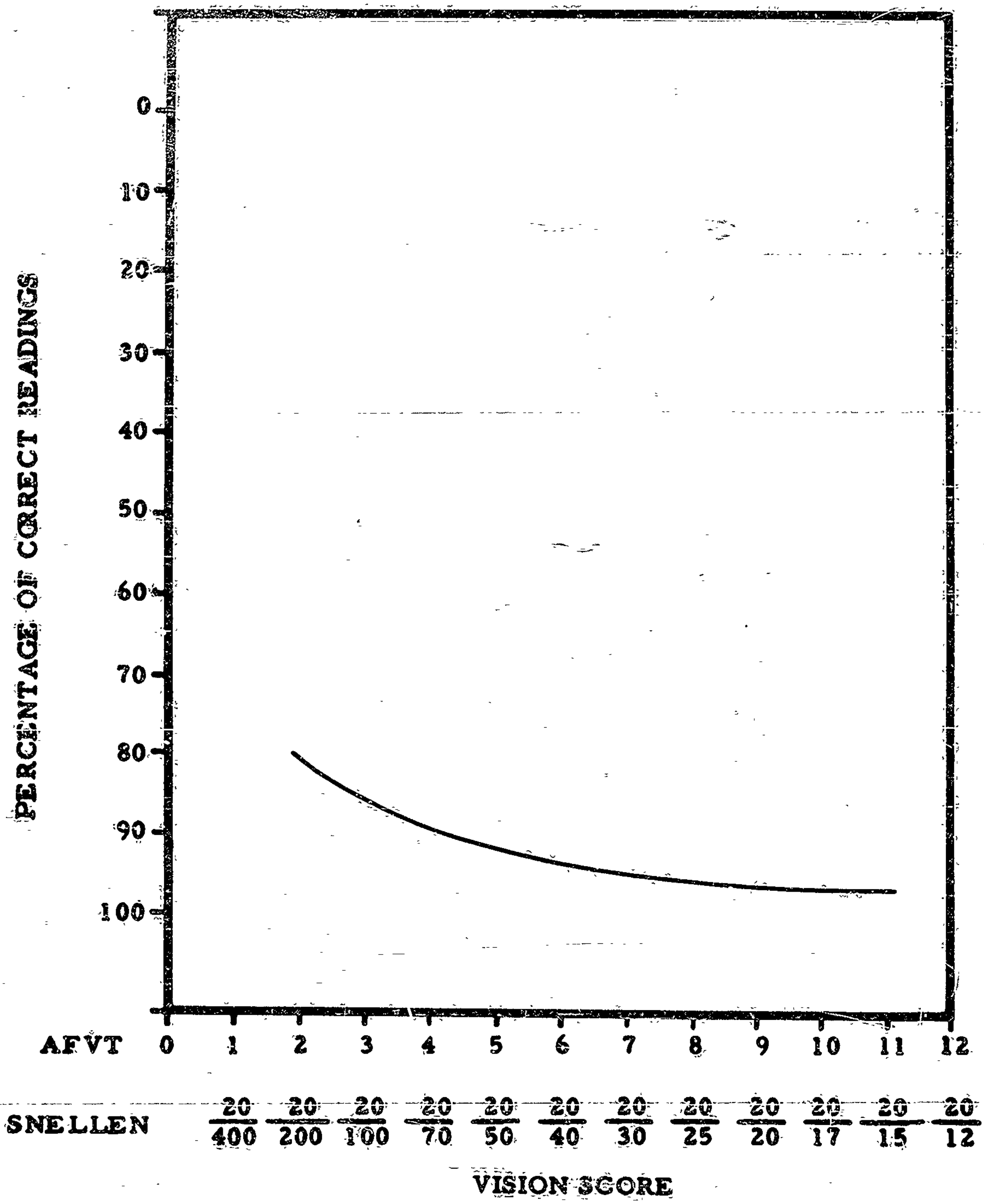

FIG. 61. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 2, DISTANCE 2.

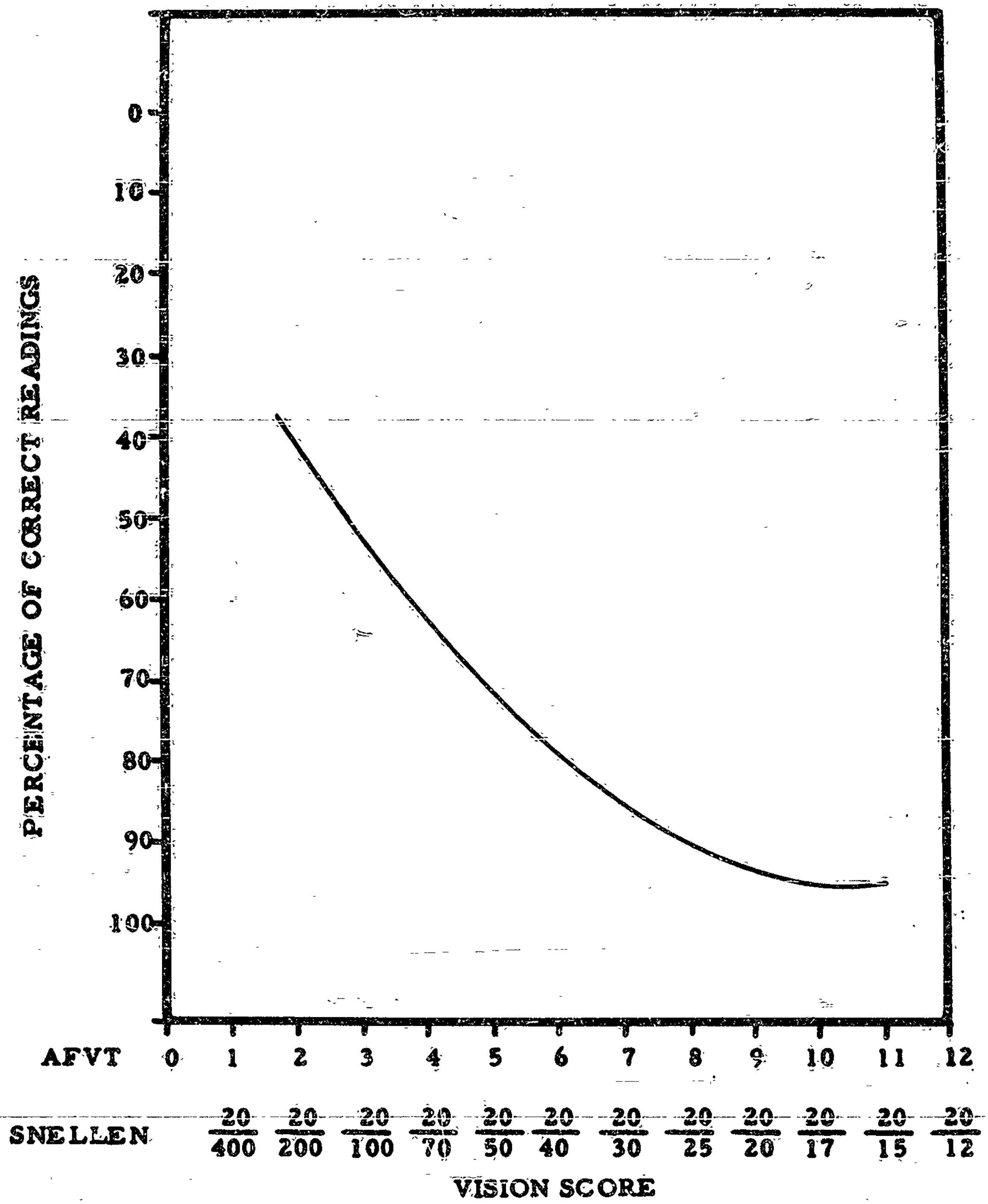

FIG. 62. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 2, DISTANCE 3.

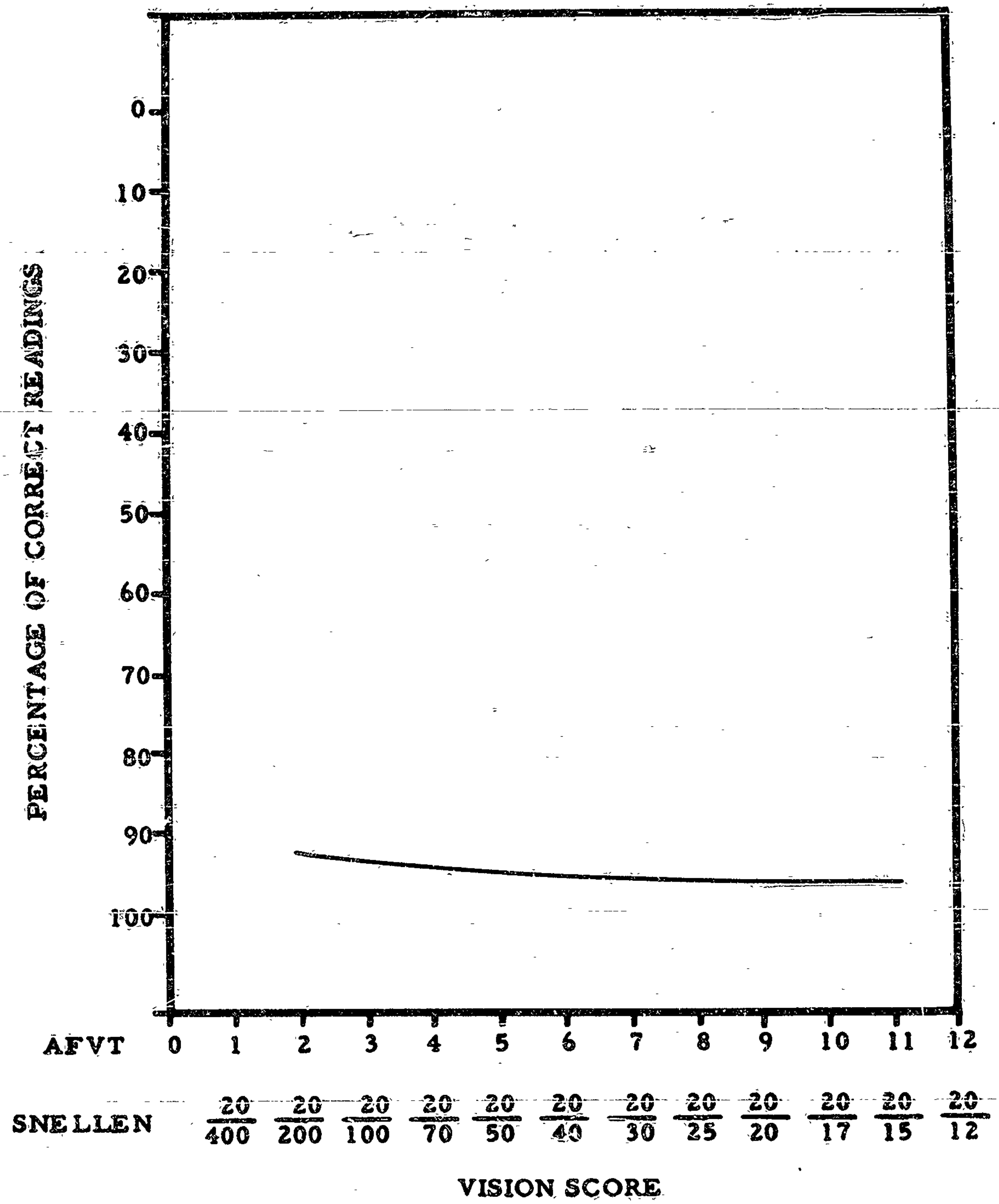

FIG.63. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 3, DISTANCE 1.

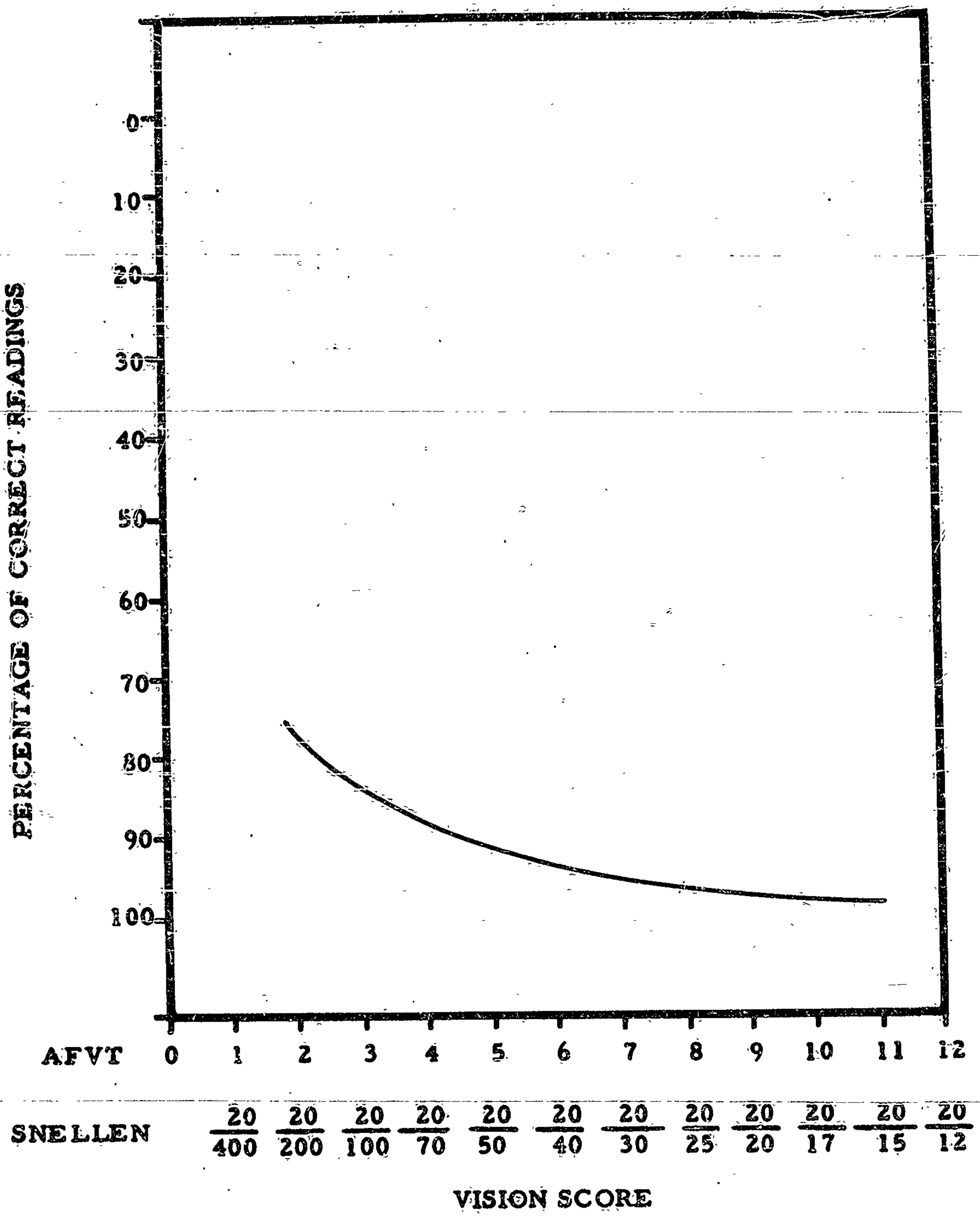

FIG. 64. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 3, DISTANCE 2.

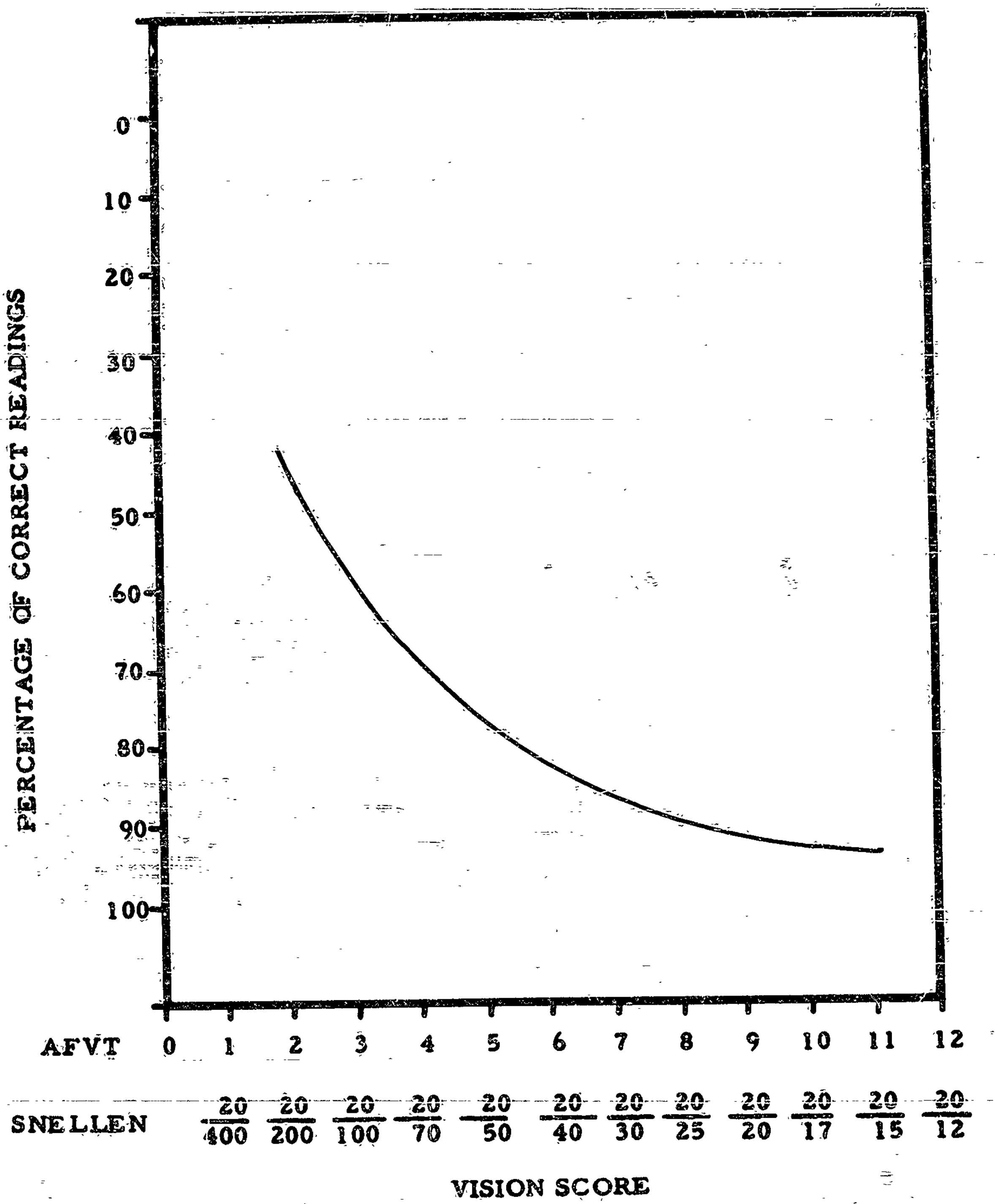

FIG. 65. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 3, DISTANCE 3.

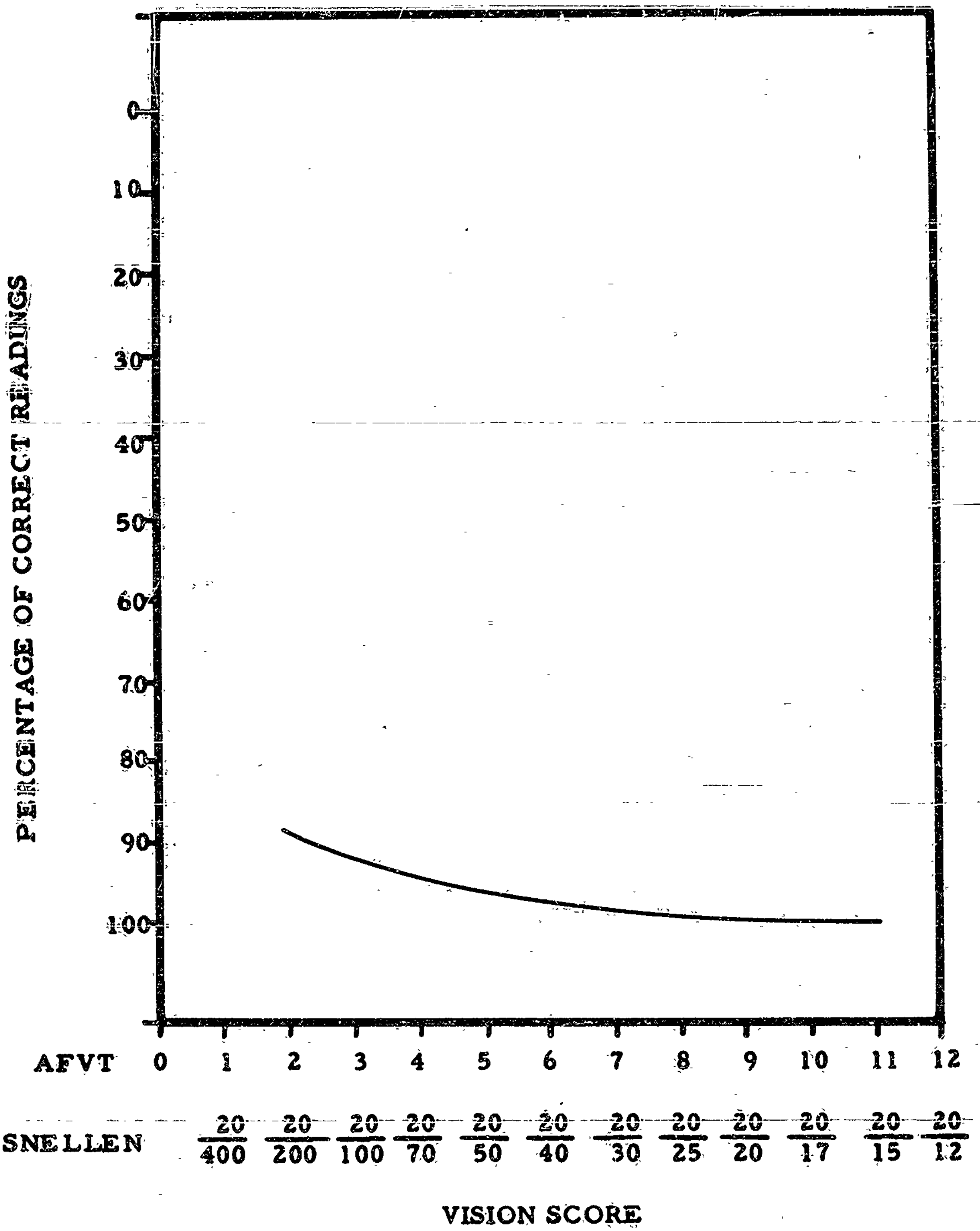

FIG. 66. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 4, DISTANCE 1.

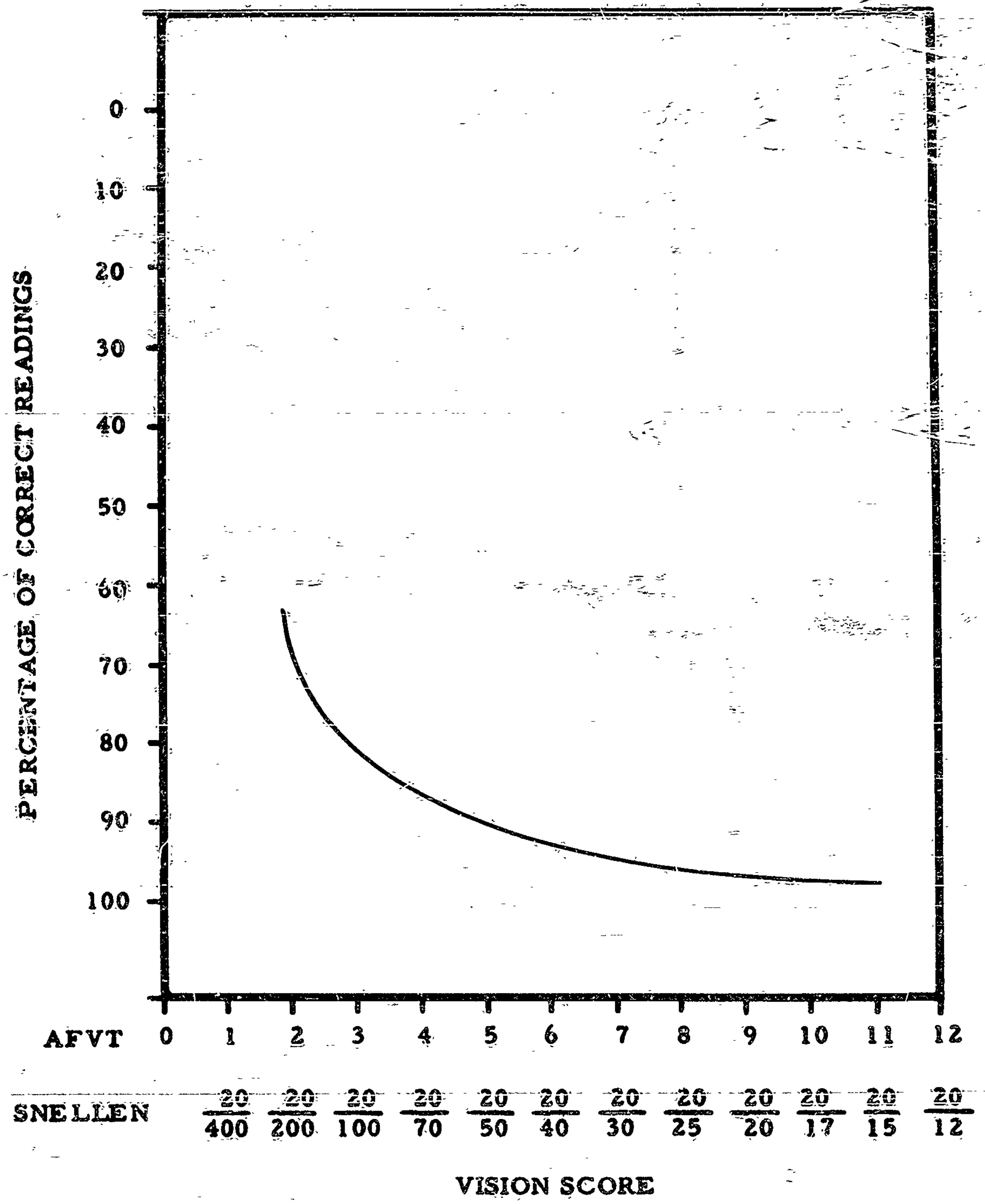

FIG. 67. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 4, DISTANCE 2.

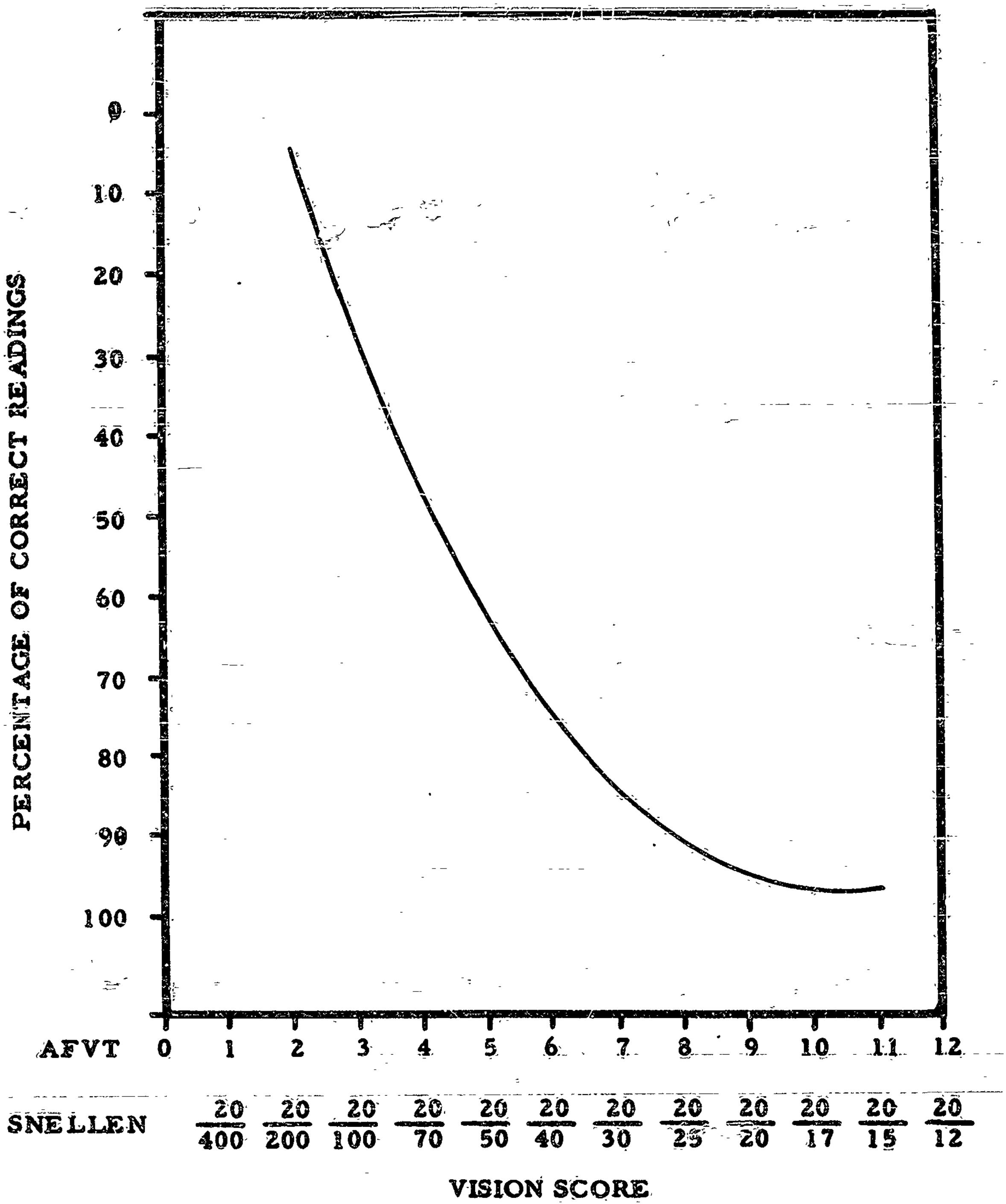

FIG. 68. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 4, DISTANCE 3.

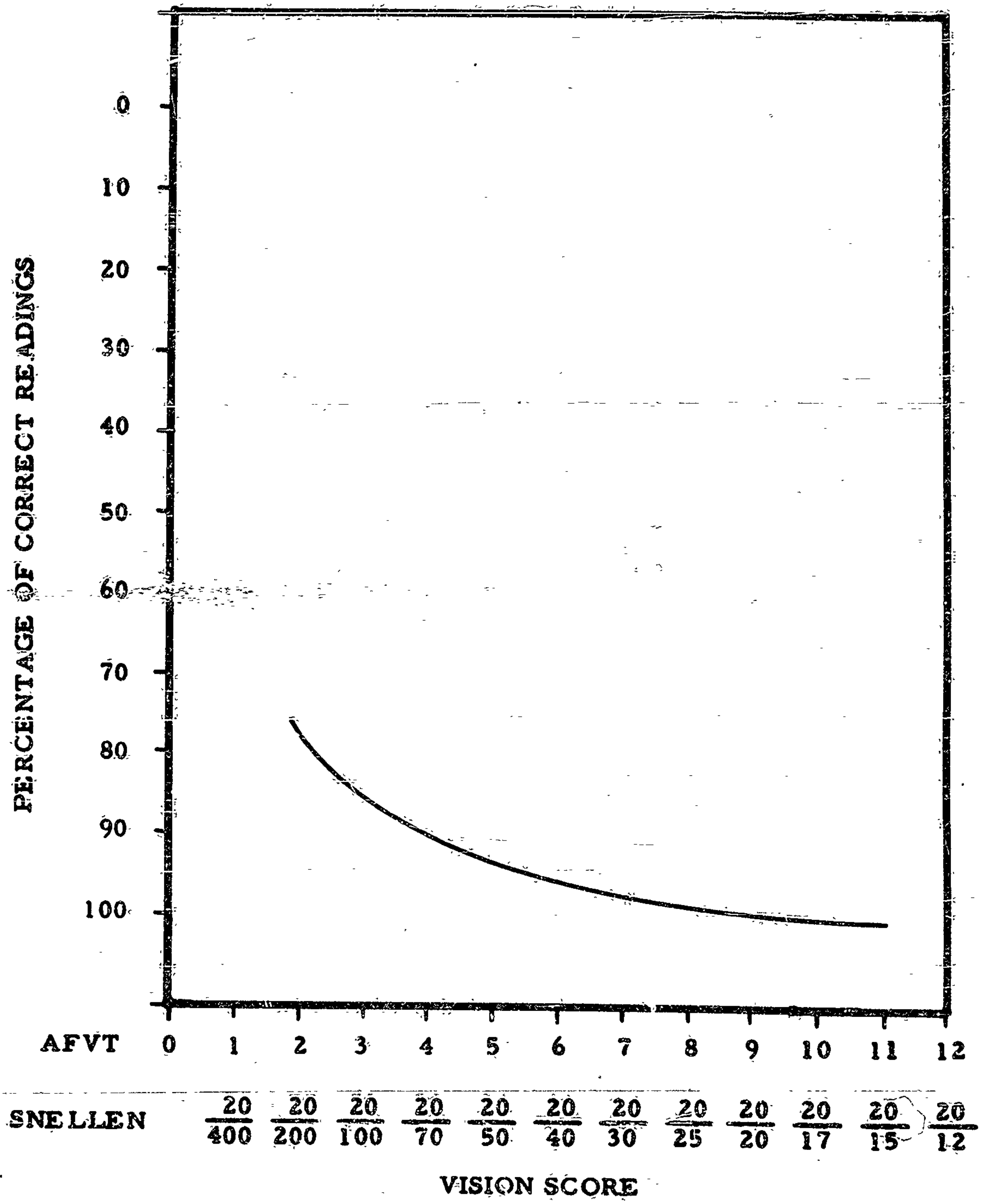

FIG. 69. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 5, DISTANCE 1.

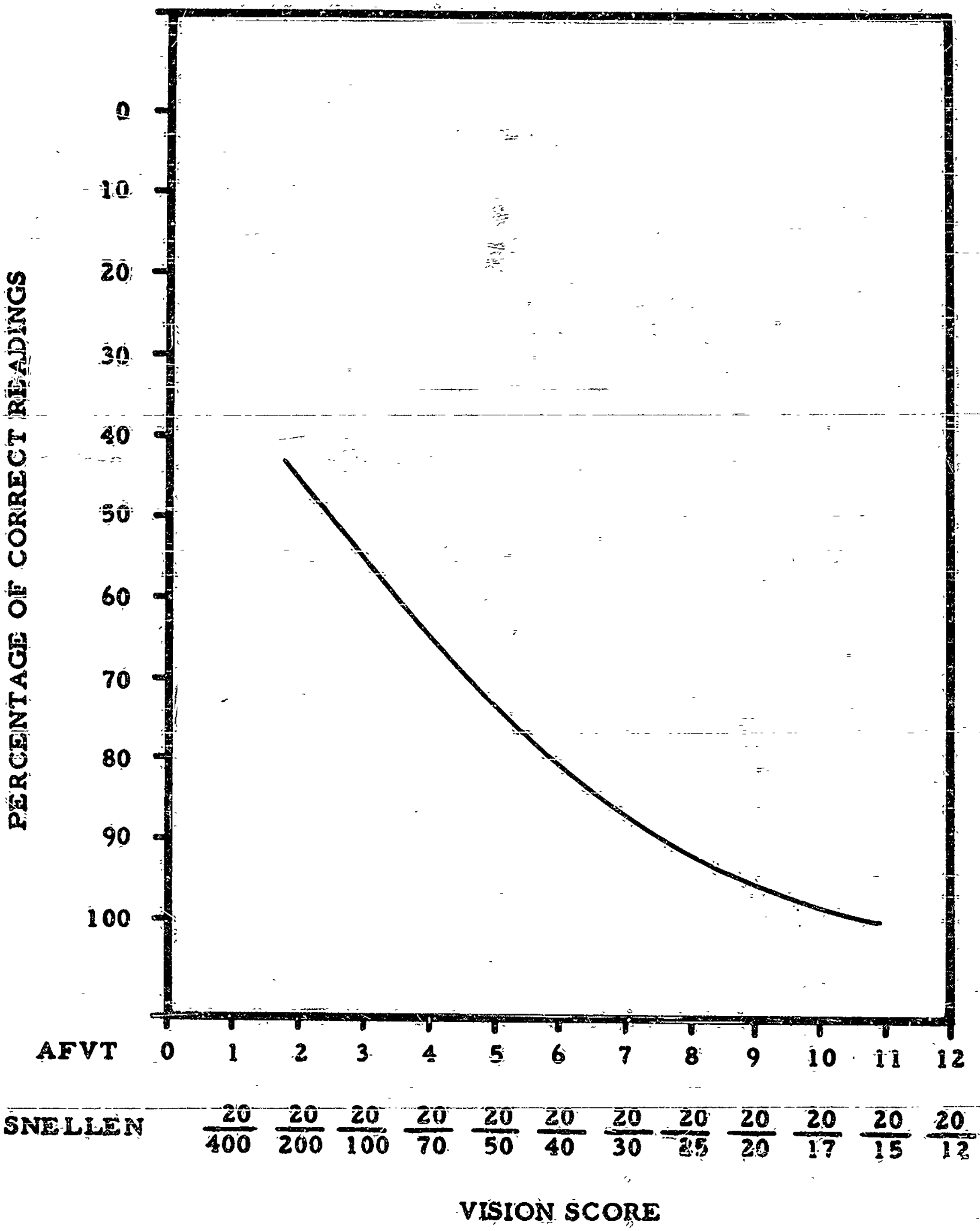

FIG. 70. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 5, DISTANCE 2.

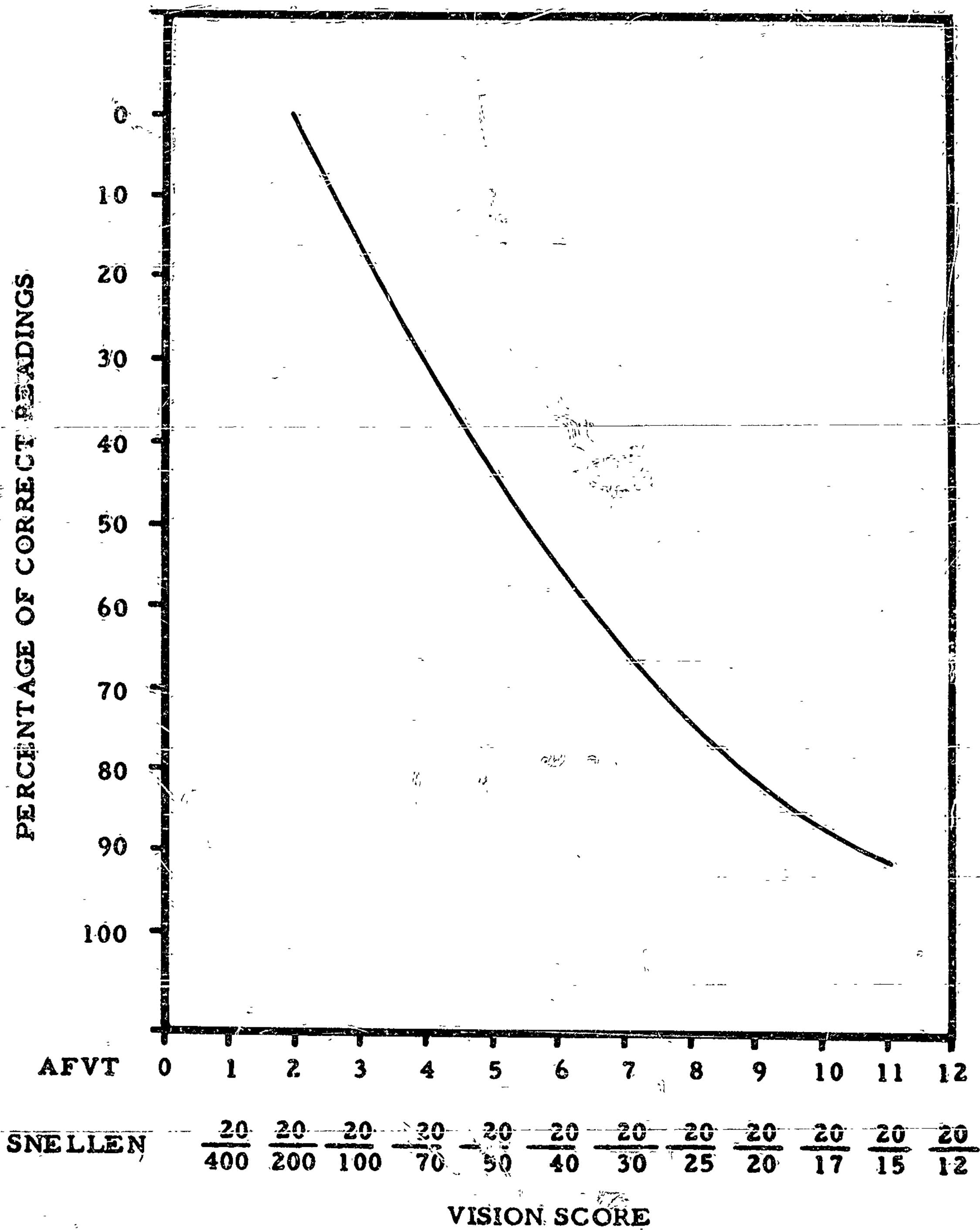

FIG. 71. RELATIONSHIP BETWEEN PERCENTAGE OF CORRECT READINGS AND BEST EYE NEAR VISUAL ACUITY SCORE ON ARMED FORCES VISION TESTER AT ILLUMINATION LEVEL 5, DISTANCE 3.

APPENDIX G

ORDER OF VISION LEVELS

APPENDIX G

Order of Vision Levels

S_1	I	II	III	IV	V
S_2	II	IV	V	I	III
S_3	III	V	I	II	IV
S_4	IV	III	II	V	I
S_5	V	I	IV	III	II
S_6	V	IV	III	II	I
S_7	IV	III	I	V	II
S_8	I	V	II	IV	III
S_9	II	I	V	III	IV
S_0	III	II	IV	I	V